PAWTUXET RIVER

RHODE ISLAND

REPORT ON SURVEY FOR FLOOD CONTROL

UNITED STATES ENGINEER OFFICE
PROVIDENCE, RHODE ISLAND

OCTOBER 20, 1939

87

REPORT ON SURVEY FOR FLOOD CONTROL

ON THE

PAWTUXET RIVER, RHODE ISLAND

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REPORT

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WAR DEPARTMENT
UNITED STATES ENGINEER OFFICE
PROVIDENCE, RHODE ISLAND

October 20, 1939

Subject: Report on Survey for Flood Control on the Pawtuxet River, Rhode Island.

To: The Chief of Engineers, U. S. Army, Washington, D. C. (Through the Division Engineer)

SYLLABUS

The District Engineer finds that the Pawtuxet River and its tributaries are subject periodically to destructive floods, and that flood control measures at certain localities are economically justified. He recommends the adoption of a flood control plan consisting of a channel in the vicinity of Pontiac to divert flood waters from the lower reaches of the river where the greatest damages occur, and local protective works at Clyde on the North Branch; all substantially as shown on the accompanying maps and drawings, and at an estimated total cost of $1,689,000, provided that local interests hold and save the United States free from damages due to the construction works; maintain and operate all the completed works; provide the necessary lands, easements, and rights-of-way for the Clyde Levee at an estimated cost of $22,000; and make a contribution of 25 percent of the total capital cost of the Pontiac Diversion Channel, not to exceed $347,500, including the cost of lands, easements, and rights-of-way, or, in lieu thereof, provide lands, easements, and rights-of-way, at an estimated cost of $79,000, concurrently construct three bridges across the diversion channel, at an estimated cost of $229,000, and make a cash contribution not to exceed $39,500. The total estimated cost to the United States is $1,319,500. He also finds that there is no economic justification for improvement for navigation, power, or pollution control.

I. GENERAL

1. AUTHORITY. - The Flood Control Act approved June 22, 1936 (Public No. 738, 74th Congress), states:

> "Sec. 6. The Secretary of War is hereby authorized and directed to cause preliminary examinations and surveys for flood control at the following-named localities . . ."

and is amended by Section 5 of the Flood Control Act approved August 28, 1937 (Public No. 406, 75th Congress), to read:

> "Sec. 5. That Section 6 of the Act : . . approved June 22, 1936, is hereby amended by adding to the list of localities at which preliminary examinations and surveys are authorized to be made, the following names:
>
> Pawtuxet River, Rhode Island."

The preliminary report was submitted on February 15, 1938. Upon recommendation of the Board of Engineers for Rivers and Harbors, a survey of the lower valley, as recommended in the preliminary report, was authorized by the Chief of Engineers by letter dated June 11, 1938. On November 15, 1938, the District Engineer requested authorization for an extension of the flood control survey to cover the entire Pawtuxet River. The extension was approved by indorsement of the Chief of Engineers dated December 2, 1938.

2. SCOPE OF THE INVESTIGATION. - This report comprises an investigation and survey of the entire watershed of the Pawtuxet River and its tributaries with a view to providing flood control. It proposes a flood control plan consisting of a levee around a locality on the North Branch of the Pawtuxet River and a diversion channel that provides complete protection against floods on the lower reaches of the main river. All methods of protection that were studied are stated and the resulting benefits shown. Data on hydrology and meteorology, geology, flood losses, and pollution, and the conclusions drawn from them, together with descriptions, estimates, and the economics of the proposed plans, are included in the report. Pertinent data, descriptions, and estimates in greater detail are given in the Appendix.

3. PRIOR REPORTS. - A preliminary report was submitted on February 15, 1938. It discussed the Pawtuxet River Basin with respect to flood control. It was based on information contained in reports by state and municipal agencies supplemented by additional data secured by this office. In this report, the District Engineer found that the Pawtuxet River Valley is periodically subject to floods, with damages occurring principally in its lower reaches, and recommended that a survey of the lower valley be made to determine the economic advisability

of flood protection by means of levees and channel improvements. Subsequent to the floods of July and September 1938, he recommended extension of the survey to cover the entire Pawtuxet River (see Paragraph 1).

4. REPORTS OF OTHER AGENCIES. - "The Water Resources of Rhode Island," printed in January 1928, is the report of a state commission appointed solely to make this investigation of the sources of water supply in Rhode Island, and includes data on the Pawtuxet River. The State Planning Board of Rhode Island in their Special Report No. 9, dated September 9, 1936, and entitled "Rhode Island Water Resources," also describes and gives data for this stream. In connection with water supply, the City of Providence has made extensive investigations of the North Branch of the Pawtuxet River and has gathered various hydrologic data. The results of these investigations and these data were used in the preparation of this report.

5. EXISTING PROJECTS. - There is no existing Federal flood control project within the Pawtuxet River Basin.

6. MAPS. -

a. The Pawtuxet River watershed is included in the quadrangle maps of the U. S. Geological Survey. These maps were used in compiling Plate 1.

b. Maps to a scale of 1:1200, having a vertical interval of ten feet, and covering the three mile reach of the river extending from its mouth to Elmwood Avenue, Cranston, Rhode Island, are also available. These maps were prepared as a Works Progress Administration (now Work Projects Administration) project under the sponsorship of the Department of Public Works of the State of Rhode Island, Bureau of Harbors and Rivers, and were used in the preparation of this report.

c. Three small areas were mapped by this office. One extends for 1,200 feet upstream from Elmwood Avenue, Cranston, the second extends along the North Branch of the Pawtuxet River for 3,000 feet at Clyde, Rhode Island, and the third is a strip approximately 1,000 feet wide extending from Pontiac to Apponaug. The first two are plotted to a scale of 1:1200 and have a vertical interval of two feet. The third is plotted to a scale of 1:4800 and has a vertical interval of ten feet.

d. At the request of the Providence office, the U. S. Army Air Corps in 1939 photographed a large portion of the Pawtuxet Watershed from the air. These pictures are at an approximate scale of 1:12000 and have been of value for reference in the preparation of this report.

II. DESCRIPTION OF PAWTUXET BASIN

7. GENERAL. - The Pawtuxet River is located in the central part of Rhode Island. It has two principal tributaries, the North and Southwest Branches. Both the main stream and the two main branches are highly developed by mill water power installations and conservation storage. The most important of these is the Scituate Reservoir, on the North Branch, which forms the source of water supply for the City of Providence.

8. LOCATION AND SIZE. - The Pawtuxet River Watershed lies entirely within the boundaries of Rhode Island and covers an area of 230.4 square miles. The basin is triangular in shape, with the stream originating along one base near the Rhode Island-Connecticut boundary and having its mouth at the apex at Pawtuxet on Narragansett Bay. The maximum width of the basin in a northerly-southerly direction is 23 miles and the length westerly from Pawtuxet is 18 miles.

9. TOPOGRAPHY. - The watershed is hilly with numerous swamps, a few natural lakes, and many ponds and reservoirs. The basin traversed by the lower four miles of the main stream has an average elevation of

40 feet above mean sea level. West of this area the terrain rises sharply for approximately 200 feet. The ascent then becomes more gradual, continuing to elevations ranging between 500 and 800 feet above mean sea level at the western divide. Durfee Hill, the highest point in Rhode Island, is on the northwestern divide. The average elevation of the entire basin does not exceed 300 feet, and increases from south to north. Much of the drainage area is wooded. The Rhode Island Department of Agriculture and Conservation reports that 37.8 square miles or 16.3 percent of the total basin was denuded by fire or by logging operations during the period 1921 - 1936. The topography of the entire drainage area is shown on U. S. Geological Survey maps drawn to a scale of 1:62,500 and having a 20-foot contour interval. Plates 1 and 2 are a map and profiles of the river and its principal tributaries.

10. DESCRIPTION OF MAIN STREAM. - The Pawtuxet River is formed by the junction of the North and Southwest Branches at Riverpoint. Thence it flows between low banks over a bed of sand and silt, northeasterly for 10.6 miles to its mouth at Pawtuxet Cove. Its average width is 100 feet; its average depth is 4 feet; and its average slope is 4.7 feet per mile, corresponding to a total fall of fifty feet from Riverpoint to the mouth.

11. DESCRIPTION OF TRIBUTARIES. - The two principal tributaries of the Pawtuxet River are the North Branch and the Southwest Branch.

a. The North Branch of the Pawtuxet River originates at Scituate Reservoir, which is fed principally by the Moswansicut and Ponaganset Rivers. Prior to the construction of Kent Dam which forms Scituate Reservoir, the North Branch was formed by the confluence of these two streams within the present Scituate Reservoir area. It flows southwesterly for 5-1/2 miles from Kent Dam to Riverpoint, where it joins the Southwest

Branch to form the Pawtuxet River. Its average slope from the tailwater of Kent Dam is 27 feet per mile, with a total fall of 149 feet. Three-quarters of this fall is developed head, resulting in a continuous succession of dams and pools.

b. The Southwest Branch is similarly formed by the junction of the Flat and Big Rivers in the Flat River Reservoir area, and originates at Flat River Reservoir Dam. Thence it flows east and north for 7.8 miles to Riverpoint. Its average slope below the tailwater of Flat River Reservoir Dam is 23.6 feet per mile, with a total fall of 184 feet. Nine-tenths of this head is commercially developed, resulting in a continuous succession of dams and pools.

c. Pertinent data on the Pawtuxet River and its principal tributaries are given in Table I.

TABLE I

Name of Stream	Miles Above Pawtuxet Cove	Miles Above River-point	Total Drainage Area Square Miles	Length Miles
Pawtuxet River	0.0	-	230.4	10.6
Pocasset River	3.5	-	26.2	10.4
Meshanticut Brook	8.6	-	15.5	7.4
North Branch	10.6	0.0	106.0	7.5
Kent Dam (Scituate Reservoir)	16.1	5.5	92.8	
Ponaganset River	18.1	7.5	53.3	10.0
Moswansicut River	18.1	7.5	32.8	12.0
Southwest Branch	10.6	0.0	73.2	8.5
Flat River Reservoir	18.4	7.8	56.7	
Big River	19.1	8.5	32.2	8.8
Flat River	19.1	8.5	22.7	7.5

12. GEOLOGY. - The basin lies almost entirely in that part of Rhode Island known as the "western uplands," which constitutes about two-thirds of the state. The lower end of the basin lying in the eastern third of the state is a lowland area adjacent to Narragansett Bay. These physiographic divisions are caused by differences in the character of underlying rock formations. The prominent upland areas in the western part of the basin are formed of resistant crystalline rocks including granite, gneiss, and schist. The lowland areas are formed in weaker sedimentary strata. Glacial deposits occur throughout the entire basin, varying from shallow thickness in the higher elevations to considerably greater thicknesses in the valleys and lower elevations. In the upland areas these glacial deposits are essentially unassorted, being composed of mixtures of sand, silt, gravel, and boulders. In the lowland areas the deposits, having been laid down by glacial stream action, are well assorted and bedded, and form extensive tracts underlain by coarse glacial outwash deposits. Other tracts are underlain largely by sand which forms extensive sand plain formations.

13. POPULATION. - Based upon the state census of 1936, the population of the Pawtuxet Watershed is estimated at 100,000. About 17 percent of this population is concentrated in and near West Warwick and about 60 percent near the mouth of the river in Cranston and an adjoining section of Providence. The population per square mile for the State of Rhode Island is about 550 and for the drainage basin of the Pawtuxet River is about 420. The high average population per square mile of drainage area is principally due to the two comparatively small areas where the population is dense. For the western half of the drainage basin the average population per square mile does not exceed 50.

14. INDUSTRIES. - The upper watershed of the North Branch is largely

controlled by the City of Providence for water supply. The waters of the upper Southwest Branch are conserved for industrial use in a number of reservoirs owned by the Quidnick Reservoir Company. These two branches join at mile 10.6 and are both highly developed for industrial purposes in their lower reaches. The mills occupying the valley are mostly devoted to the manufacture of textile products. The industrial statistics in Table II are taken from the latest available information, principally the Federal Census of 1930. The principal manufacturing plants in the watershed are located in or near West Warwick and Cranston.

TABLE II

MANUFACTURING ESTABLISHMENTS

	Number of establishments	Number of workers*	Wages*	Cost of raw materials, power, etc.	Value of finished goods
State of Rhode Island	1,701	126,068	$144,196,934	$342,290,071	$666,368,210
Pawtuxet Watershed	70	9,600	10,600,000	25,900,000	48,300,000
Percent of state total	4.1	7.6	7.3	7.5	7.2

*Does not include salaried employees.

15. AGRICULTURE. - Much of the lower 10 miles of the Pawtuxet Valley is marshy and subject to overflow. Some of the land is used for pasturage; the drier portions are cultivated. Table III contains agricultural statistics compiled from data contained in the Federal Census of 1930:

TABLE III

	Population	Area in farms (acres)	Value of crops	Value of dairy products	Total value of crops, livestock, and dairy products
For State of Rhode Island	687,497	279,361	$1,475,787	$6,183,126	$ 9,910,534
For Pawtuxet Watershed	100,000	48,900	231,000	1,205,000	1,900,000
Percent of state total	14.5	17.5	15.6	19.5	19.2

16. TRANSPORTATION FACILITIES. - Highways and railways provide all sections of the drainage area with adequate means of freight and passenger transportation. An extensive system of modern hard-surfaced highways covers practically all portions of the Pawtuxet Basin. The New York, New Haven and Hartford Railroad occupies the main valley of the Pawtuxet River and also operates a line along the North Branch as far as Hope. Another line of the same railroad closely follows the Southwest Branch throughout its length and connects Providence, Rhode Island, and Hartford, Connecticut, via Willimantic, Connecticut. The main shore-line route of this railroad between Boston and New York passes through the lower end of the watershed. The locations of these railroad lines are shown on Plate 1.

17. INDUSTRIAL DEVELOPMENT OF WATER RESOURCES. -

a. Industrial power. - Certain reaches of the Pawtuxet River and its principal tributaries have been highly developed either for water supply or for power. North Branch falls 147 feet in its lower four miles and Southwest Branch falls 182 feet in its lower six miles. These two reaches are characterized by rapids and falls with ledge outcrops furnishing excellent foundations for dams. During colonial times many grist and saw mills were built. These were eventually supplanted by textile mills which, for the most part, now utilize the stream. While the water power available at the various dam sites is considerable, and used to some extent, the most important use of the water at the present time is for the washing and processing required in the manufacture of wool and cotton textile fabrics. The additional power required by the mills is furnished by steam plants, or electrical energy purchased from local power companies. The storage capacity at the power dams is of very minor importance. The mills utilize storage reservoirs on the upper reaches. Table IV gives pertinent data on power privileges:

TABLE IV

POWER DEVELOPMENTS

*No.	Location	River		Name of Owner	Rated capacity of water wheels (horsepower)
4	Pontiac, R. I.	Pawtuxet		B.B. & R. Knight Corp.	175
5	Natick, R. I.	"		Ralph L. Loomis	1,270
17	Clyde, R. I.	North Branch		Riverpoint Lace Works	109
19	Phenix, R. I.	"	"	Lonsdale Co.	403
20	Harris, R. I.	"	"	Interlaken Mills	291
21	Interlaken, R. I.	"	"	Interlaken Mills	223
23	Hope, R. I.	"	"	Falvey Laundry Co.	156
24	Hope, R. I.	"	"	Lonsdale Co.	506
25	Kent Dam, R. I.	"	"	City of Providence	2,200
6	Riverpoint, R. I.	Southwest Branch		Bradford Soap Works	125
7	Riverpoint, R. I.	"	"	Saybrooke Mfg. Co., Inc.	676
8	Arctic, R. I.	"	"	Westover Fabrics, Inc.	1,117
9	Centerville, R. I.	"	"	Centerville Realty Co.	736
10	Crompton, R. I.	"	"	Crompton Co.	660
11	Crompton, R. I.	"	"	Crompton Co.	518
12	Quidnick, R. I.	"	"	King Richard Mills, Inc.	456
13	Quidnick, R. I.	"	"	Quidnick Dye Mills, Inc.	600
14	Anthony, R. I.	"	"	Berkshire Fine Spinning Assn.	850
				Total	11,071

*Numbers refer to the locations of dams as shown on Plates 1 and 2.

b. Conservation. - In about 1846, certain mill owners and other interested parties, situated on the lower reaches of the Southwest Branch and on the main river, formed the Quidnick Reservoir Company. Its purpose was to construct storage reservoirs to maintain a more constant flow of water for the mills of the company members. The first reservoir, Quidnick, was constructed about 1846, followed by Tiogue Reservoir about 1858 and Flat River Reservoir about 1870. This system of reservoirs has been, and still is, of the greatest importance to the many mills below. The continued existence and economical operation of these mills is dependent to a large extent on an adequate and dependable supply of water. The Quidnick Reservoir Company has been very successful in meeting the needs of the water users. The original storage reservoirs on the North Branch have largely lost their function because of the water supply development at Scituate Reservoir downstream. Table V gives pertinent data on storage reservoirs:

TABLE V

STORAGE RESERVOIRS

Reservoir	River	Drain. area: sq. miles Gross	Net	Pond area acres	Storage capacity Acre feet	Inches on net area	Inches per foot surcharge
Ponaganset*	North Branch and Tributaries	2.1	2.1	245	4,600	41.2	2.0
Moswansicut	do	3.9	3.9	282	2,194	10.5	1.3
Coman	do	2.6	2.6	29	384	2.8	0.2
Regulating	do	22.3	15.8	242	1,292	1.5	0.3
Barden	do	33.0	33.0	240	2,618	1.5	0.1
Westconnaug	do	4.0	4.0	174	1,390	6.5	0.8
Scituate	do	92.8	33.5	3,600	77,185	43.2	2.0
Quidnick	Southwest Branch and Tributaries	2.1	2.1	180	1,614	14.5	1.6
Coventry	do	5.8	3.7	300	1,200	6.1	1.5
Carr Pond	do	0.6	0.6	100	300	9.3	3.1
Flat River	do	56.7	50.3	974	6,100	2.3	0.4
Tiogue	do	2.5	2.5	267	1,500	11.2	2.0
Total			154.1		100,377		

*Obsolete dam. Gates removed, acting as a retarding basin.

18. <u>WATER SUPPLY</u>. - In 1870 the City of Providence established its first public water supply system. A pumping station was built at this time on the lower Pawtuxet at Pettaconsett. This site was abandoned in 1926 upon the completion of Scituate Reservoir on the North Branch of the Pawtuxet River. In connection with this old pumping station, a dam was built at an old mill dam site near Broad Street at Pawtuxet in order to prevent salinity intrusion and to compensate for lowering of the water level by the pumping station. The 1915 Water Act of Rhode Island which authorized the development of Scituate Reservoir also required the city to rebuild and maintain this dam. Other water systems within the drainage

area include the Pawtuxet Valley Water Company and the Warwick and Coventry Water Company. The Pawtuxet Valley Water Company serves the villages in the valley of the North Branch of the Pawtuxet River. The company has two small impounding reservoirs on a tributary brook at Fiskeville. The Warwick and Coventry Water Company serves the villages on the Southwest Branch of the Pawtuxet River, the water supply being taken from Carr Pond located in the southeasterly part of the watershed. These two water companies are now owned and operated by the New England Water, Light, and Power Association. Over half of the population of Rhode Island receives its domestic water supply from the Pawtuxet Basin, and for this reason it is the most important river system in the state although it is third in order of size. The basin has been highly developed for water power and for industrial water supply, but its utilization for domestic water supply is of the greater importance.

19. RECREATION. - The Ilkiuma Canoe Club and a canoe livery at Pawtuxet utilize the pool formed by the Broad Street dam for canoeing. Fishing is limited by industrial development to the headwaters of streams and ponds. There are a few private cottages located on these ponds. In Cranston, the Pawtuxet River Reservation has a park, playground, and baseball diamonds on the flood plain of the river.

20. WILD LIFE. - There is little wild life on the Pawtuxet. A few deer are found in the less populated areas and are protected by a year-round closed season. Birds are not plentiful, and hunting is limited to small game.

III. HYDROLOGY AND METEOROLOGY

21. CLIMATE. - The climate of the valley is temperate. The summers are not marked by excessive heat and the winters are generally mild. Extreme hot spells in summer and cold periods in winter are usually of short

duration. The eastern end of the watershed, owing to the tempering influence of nearby Narragansett Bay, has somewhat milder winters than the higher western part. The continuous record of temperatures at Providence, Rhode Island, is available from 1904 to date. During this period the absolute maximum recorded temperature was 100 degrees and the absolute minimum recorded temperature was 17 degrees below zero. The mean annual temperature is 51.8 degrees.

22. PRECIPITATION. - The average annual precipitation on this watershed is about 45 inches, including the water equivalent of the snowfall. Extremes of low and high annual precipitation, according to the records of the Providence City Engineer, occurred in 1846 with a low of 30.51 inches and in 1896 with a high of 63.50 inches. Tables VI and VII list the mean annual and monthly precipitation for typical stations:

TABLE VI

Station	Location	Period of record	Mean annual (Inches)
A	Providence, R. I.	1832 - 1930	45.04
B	Providence, R. I.	1905 - 1938	38.23
C	Kingston, R. I.	1889 - 1938	50.38
D	Flat River Reservoir Coventry, R. I.	1930 - 1936	46.48
E	Scituate Reservoir	1916 - 1925	47.96

TABLE VII

MEAN MONTHLY PRECIPITATION IN INCHES

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	4.10	3.83	4.09	3.82	3.62	3.26	3.48	4.07	3.31	3.57	3.90	3.99
B	3.59	2.90	3.27	3.33	2.87	3.13	3.27	3.45	3.36	2.80	2.90	3.36
C	4.86	4.28	4.70	4.60	3.90	3.49	3.36	4.27	3.93	4.06	4.23	4.70

Station A. - City Engineer's record observed from 1832 to 1876, inclusive, on College Hill, Providence, Rhode Island, and compiled under the direction of the late President Alexis Caswell of Brown University. From 1876 to 1930, observations were made at Hope Reservoir in Providence, and compiled under the direction of the City Engineer.

Station B. - Records of U. S. Weather Bureau, Providence, Rhode Island.

Station C. - Rhode Island State College, U. S. Weather Bureau Substation, Kingston, Rhode Island.

Station D. - Private gage owned and maintained by Quidnick Reservoir Company. Gage located at Flat River Reservoir Dam.

Station E. - Records of City of Providence. Gages in Scituate Township.

23. SNOWFALL. - The average annual snowfall for the State of Rhode Island varies greatly with location, as there is a steady increase from the coast to the interior. On the Pawtuxet Watershed the variation is not so great, the average annual snowfall being 35 to 40 inches, with a water equivalent of about 4 inches.

24. CHARACTERISTICS OF STORMS. - Two general types of storms occur in New England, continental storms and tropical hurricanes. The continental storms originate over the United States and southwestern Canada, and move in a general easterly and northeasterly direction. The storms occur in every season of the year. The tropical hurricanes originate over the Atlantic Ocean, including the Caribbean Sea and the Gulf of Mexico, and generally move in a westerly or northwesterly direction, recurving to the north or northeast as they approach the New England coast. This type of storm can be expected in any month from May to December, but by far the greater number occur in August, September, and October. They seldom reach New England with destructive force, but when they do, excessive precipitation occurs.

25. RUN-OFF. - In connection with studies incident to the construction of Scituate Reservoir for the Providence water supply, a stream gaging station was established in January 1916 at Fiskeville on the North Branch, with a drainage area of 101.8 square miles. The records for Fiskeville have been published by the U. S. Geological Survey for the period from

1916 to 1925. The subsequent records have not been published, but are available in the files of the Providence Water Works. Only one other station has been established in the watershed. That station was at Harris, not far from the present station at Fiskeville. It was in operation from August 1909 to June 1911, only. The records have been withheld owing to insufficient rating, and are of no practical value. Table VIII shows the results of operation of the Fiskeville station from 1916 to 1925:

TABLE VIII

Period of years	Discharge (second-feet) Max.	Min.	Mean values for period Rainfall (inches)	Run-off (inches)	Percent of run-off to rainfall
1916-1925	2,762	1.2	47.72	27.18	56.96

26. INFLUENCE OF TOPOGRAPHY ON RUN-OFF. - The Pawtuxet basin is triangular in shape, and its multi-stream pattern is conducive to synchronism of tributary flood crests from the various branches. The moderate heights of the hills and the moderate slopes of the streams in the headwaters tend to delay the rate of accumulation of flood waters. The intensity of peak discharge is further modified by the natural valley storage in the wide, flat valleys and many swamps in all parts of the watershed. The stream slopes in the extreme lower valley are flat, producing low velocities and consequently high flood stages.

27. INFLUENCE OF DEVELOPMENTS ON RUN-OFF. - The developments that affect floods consist of storage reservoirs, run-of-river plants, and bridges with restricted water channels.

a. Storage reservoirs. - As shown in Table V, existing reservoirs have a storage capacity of over 100,000 acre-feet on a total drainage area of 154 square miles, or 65 percent of the drainage area of the watershed. While neither designed nor operated for flood control, these reservoirs have modified high flood stages on the lower reaches of the Pawtuxet River. The last column in Table V shows for each reservoir the storage in terms of inches of depth on its net drainage area per foot of surcharge or head on its spillway. This figure serves as an index of the flood control storage that is obtained when the reservoirs are full at the beginning of any flood. For the largest reservoir, Scituate, which was completed in 1926, it can be seen that a surcharge of 3 feet will provide a storage volume of 6 inches, which would result in a high degree of control of its net drainage area. A lesser degree of control is obtained at the second largest reservoir, Flat River, with a similar surcharge. The operating records for these two reservoirs show that a considerable portion of the run-off during past floods was stored below their spillway crests, notably as shown in Table IX:

TABLE IX

PERCENT OF FLOOD RUN-OFF RETAINED IN PAST FLOODS

Date of flood	SCITUATE RESERVOIR Drainage area = 92.8 square miles: Storage below crest: Acre feet	Inches	Percent of run-off	Surcharge storage: Acre feet	Inches	Percent of run-off	Total percent of run-off stored	FLAT RIVER RESERVOIR Drainage area = 56.7 square miles: Storage below crest: Acre feet	Inches	Percent of run-off	Surcharge storage: Acre feet	Inches	Percent of run-off	Total percent of run-off stored
Feb.1886	Before construction							1450	0.48	10	4570	1.51	30	40
Nov.1927	18,400	3.72	100	0	0	0	100	3190	1.06	30	810	0.27	7	37
Mar.1936	15,870	3.21	60	7270	1.47	28	88	0	0	0	2310	0.76	14	14
July1938	0	0	0	6450	1.30	37	37	325	0.11	5	1300	0.43	19	24

b. Run-of-river plants. - The run-of-river plants on the tributaries and main stem have a negligible effect on flood discharges. They have occupied part of the flood plain naturally devoted to valley storage and in return have provided surcharge storage in backwater above them.

Flood heights are increased locally at each dam. As previously mentioned, a low dam on the Pawtuxet River 400 feet above its mouth at Pawtuxet Cove was constructed to prevent salinity intrusion and to compensate for lowering of the water level by the Pettaconsett pumping station once operated for water supply for the City of Providence. The pumping station was abandoned in 1926. This dam increases moderate flood heights one or two feet, the effect disappearing at the old dam of the Pettaconsett pumping station.

c. Bridges and buildings. - For severe floods, the Broad Street bridge just below the Pawtuxet Dam becomes the control affecting the lower three miles of the river, increasing natural flood heights an additional amount. Other bridges and buildings have localized effects only.

28. INFLUENCE OF TIDE ON RUN-OFF. - It is possible for high tides, augmented by hurricane winds, to produce stages at the mouth of the Pawtuxet River high enough to overflow the dam above Broad Street (see Paragraph 27 b) and to cause flood losses upstream. The crest of the Pawtuxet Dam is 5.2 feet above mean sea level. The tidal wave of September 1938 reached an elevation of 15.4 feet above mean sea level, and raised river stages upstream as far as Pontiac. However, the Pawtuxet River was not in flood at the time the tidal wave occurred, and very little damage resulted. Channel capacities were not exceeded above Elmwood Avenue. Below Elmwood Avenue, the cellars of an unoccupied factory, two dance halls, a few homes, and about fifty acres of farm land were flooded.

IV. FLOOD DATA

29. HISTORICAL STORMS AND FLOODS. - Great storms in Rhode Island of historical record and the disastrous floods resulting from them are as follows:

a. January 21, 1801. - This was a local flood which destroyed 37 buildings in the City of Providence. Strictly speaking, this was not a flood but rather was the effect of high winds coming from the south, which brought the waters of Narragansett Bay into the streets of Providence. The loss was estimated at $300,000.

b. September 22-23, 1815. - This storm was similar to the storm of 1801 except that it was much more severe. The tide at Providence rose to almost 12 feet above normal high water, 7 feet higher than any previous record. It is reported that vessels were driven from their moorings, and many wharves, stores, houses, and barns were destroyed. No record of damages resulting from heavy precipitation or run-off could be found.

c. October 3-4, 1869. - This storm centered in central Massachusetts and Connecticut and caused a moderate flood in the Pawtuxet Watershed. In addition to the usual flooding of the lowlands, a bridge in Coventry was destroyed and railroad traffic was interrupted for a short time.

d. March 28, 1877. - According to the Providence Daily Journal of March 29, 1877, this storm caused no great loss in the Pawtuxet Basin. The paper states that the river banks were full and that the lowlands were flooded. Mills were reported as being troubled with backwater.

e. February 11-14, 1886. - This storm centered in southern New England. Most of the precipitation occurred during a 48-hour period. From 7 to 8 inches of rainfall, increased by melting snow estimated to be equivalent to 2 inches of rainfall, produced the most severe flood ever recorded on the Pawtuxet River. The flood stage resulting from this storm was about 7 feet higher than the 1936 flood in the lower Pawtuxet Valley.

f. November 2-4, 1927. - A storm rainfall of from 2 to 7-1/2 inches was reported for the Pawtuxet drainage area. As conditions were favorable for a fairly rapid run-off, a freshet was produced that caused minor damages.

g. September 16-17, 1932. - The average rainfall as determined by the City of Providence for the 92.8 square miles drainage area above Scituate Reservoir based upon the records of five stations, was 10.24 inches. The center of this storm was near the western half of the Pawtuxet Basin. The maximum recorded rainfall within the watershed was 11.89 inches. 150 square miles of the watershed received an average of 10.0 inches of rainfall with the remainder of the watershed, 82 square miles, receiving between 8 and 9 inches of rainfall. This precipitation occurred within a period of 20 hours and was the heaviest recorded for any one storm during the past 103 years. The storm occurred after an extended dry period, and reservoir levels were very low. Run-off conditions were therefore unfavorable for a rapid run-off and extensive storage capacity was also available. Consequently no unusual high river stages were experienced. Only one small item of flood loss could be found.

h. November 11, 1932. - This storm occurred at a time when conditions were favorable for a rapid run-off. Ponds and reservoirs had small storage capacity available. Rainfall ranging from 1 to 5 inches for the watershed caused a minor flood in the lower reaches of the Pawtuxet River. Lowlands were flooded and minor losses occurred including the flooding of cellars in several homes.

i. March 9-21, 1936. - The New England floods resulting from this storm were caused by a combination of heavy rainfall, deep snow cover, and unusually high temperature for the season. The Pawtuxet Watershed lies east of the path of this storm. Rainfall for the watershed for the period March 9-12 is estimated at 3.38 inches, and for the period March 18-22 at 3.06 inches. The water equivalent of the snow cover, which was depleted from the drainage area during the entire storm period, is estimated at 1 inch. The estimated run-off was 70 to 80 percent of the rainfall. The peak discharge of the flood was reduced by reservoirs and surcharge storage in Scituate and Flat River Reservoir (see Table IX).

j. July 18-24, 1938. - This storm was a coastal storm centered over southern New England and diminishing in intensity as it passed inland. An average of 7 inches of rain fell over the Pawtuxet Watershed. The run-off varied from 35 to 50 percent and resulted in a flood of approximately the same magnitude as that of March 1936. While very little of the flood was stored in Flat River and Scituate Reservoirs, the flood peaks were modified in passing through the surcharge storage of these reservoirs.(see Table IX).

k. September 17-22, 1938. - This storm was centered sixty miles to the west of the Pawtuxet Watershed. It was caused by a prolonged low pressure area over western New England, with warm moist air entering from the south. The same low pressure area caused the disastrous hurricane of September 21st to veer inland across New England, resulting in an abnormally high tide or tidal wave which exceeded by 2 feet the similar hurricane tide levels of September 1815, and caused great damage and loss of life in Rhode Island. The 1938 hurricane tide overtopped the Pawtuxet Dam 10.2 feet and flooded the lowlands along the lower Pawtuxet River. The rainfall of the preceding four days averaged 5 inches over the Pawtuxet Watershed, but reservoir levels were low, and no damaging flooding occurred from the stream run-off.

30. MAXIMUM PREDICTED FLOOD. - The greatest flood of record (period 1877 to 1939) occurred in February 1886. It reached a peak of almost 14

feet over the crest of the Pawtuxet Dam, 7 feet higher than the crests of March 1936 and July 1938. For a flood of the magnitude of 1886 in the lower river to be repeated, a much higher natural run-off than occurred at that time would be required, because of the modifying effects of Scituate Reservoir. Rainfall of the volume and intensity of the September 1932 storm, occurring at a time favorable to high run-off, would possibly produce a flood equal to that of 1886 even with present storage in operation; and a rainfall equal to that of September 1938, under the same conditions, would produce a flood in excess of that of 1886. The maximum predicted flood at points on the Pawtuxet River has been computed, based on the following assumptions:

a. The use of unit graphs for all tributaries and local inflow.

b. A rainfall volume equal to the maximum total rainfall which occurred during the storm of September 1938 on an area equal to the drainage area involved. This storm is the maximum storm of record in New England.

c. A rainfall duration of 72 hours.

d. A rainfall distribution proportional to that determined by the U. S. Weather Bureau in a recent study of rainfall in New England.

e. A run-off factor of 80 percent.

Table X gives data on past floods and the maximum predicted floods at five points in the Pawtuxet Watershed. Comparative values are given for natural conditions, i.e., no storage whatsoever, and for the conditions actually existing at the time the flood occurred.

(See Table X on following page)

TABLE X

Flood	Volume in inches of run-off: Natural	Volume in inches of run-off: Mod. by existing storage	Stage in feet: Natural	Stage in feet: Mod. by existing storage	Peak discharge in c.f.s.: Natural	Peak discharge in c.f.s.: Mod. by existing storage	Probable frequency in years
	North Branch at Clyde (D. A. = 106.0 Sq. Mi.)						
Feb. 1886	5.05	5.05	14.05	13.30	9660	8490	82
*Mar. 1936	3.80	1.35	13.35	6.00	8620	1270	59
July 1938	3.55	3.55	10.80	8.88	5450	3520	16
Max.Predicted	12.78	12.78	23.02	19.90	25200	19400	1900
	Southwest Branch at Anthony (D. A. = 73.2 Sq. Mi.)						
Feb. 1886	5.05	4.66	7.85	6.47	7750	5800	220
*Mar. 1936	3.80	3.80	5.37	5.04	4390	3990	42
July 1938	2.32	2.23	3.32	3.20	2110	2000	6
Max.Predicted	12.91	12.91	10.5	10.03	11900	10110	780
	At Pontiac (D. A. = 194.7 Sq. Mi.)						
Feb. 1886	5.05	4.90	8.65	7.77	17550	14150	130
*Mar. 1936	3.80	2.47	7.32	4.65	12690	5360	49
July 1938	3.09	2.86	5.77	4.95	7990	6020	14
Max.Predicted	12.41	12.41	12.36	11.12	35000	28700	1100
	At Elmwood Avenue (D. A. = 220.9 Sq. Mi.)						
Feb. 1886	5.05	4.92	23.5	21.65	19930	15320	143
*Mar. 1936	3.80	2.62	20.2	17.45	12210	7130	34
July 1938	3.14	3.11	18.9	17.65	9440	7500	17
Max.Predicted	12.43	12.43	33.6	29.20	38020	30710	1000
	At Mouth, Pawtuxet (D. A. = 230.4 Sq. Mi.)						
Feb. 1886	5.05	4.92	19.00	16.10	20850	16070	148
*Mar. 1936	3.80	2.66	14.05	11.95	11620	7700	27
July 1938	3.16	3.13	12.60	11.96	9950	7790	18
Max.Predicted	12.41	12.41	37.00	27.90	40140	31490	1000

*First peak of March 1936 flood only.

31. The rainfall volume used to compute the maximum predicted flood at the points listed in Table X varies from 16.14 inches on an area of 73.2 square miles, to 15.52 inches on an area of 230.4 square miles, with depths of run-off of 12.91 inches to 12.42 inches. The maximum predicted flood discharges, unmodified by existing storage, vary from 25,200 cubic feet per second (238 c.f.s. per sq. mi.) at Clyde on the North Branch to 40,140 cubic feet per second (174 c.f.s. per sq. mi.) at the mouth of the main stream. Including the effects of existing storage, these discharges

are computed to be 19,400 cubic feet per second (183 c.f.s. per sq. mi.) and 31,490 cubic feet per second (137 c.f.s. per sq. mi.) respectively. The modifying effect of the existing storage is most pronounced on the North Branch below Scituate Reservoir. It should be noted that the maximum predicted flood discharges modified by existing storage are approximately four to five times greater than the July 1938 flood discharges.

V. FLOOD LOSSES

32. GENERAL. - Overflow of lowlands along the Pawtuxet is a regular occurrence during spring freshets. Moderate losses have resulted from the recent floods of March 1936 and July 1938 and from many other floods which have exceeded the normal freshet stage. The outstanding flood was that of February 1886, which greatly exceeded any recent floods and caused extensive damage. Only incomplete records are available for the losses of 1886 and other early floods. Losses of March 1936 and July 1938 have been thoroughly investigated and form the basis for the computation of average annual losses, and benefits to be derived from flood control measures. These benefits form the principal economic justification for flood protection.

33. FLOOD AREA. - Moderate floods of the magnitude of the March 1936 and July 1938 floods overflow extensive areas below the village of Natick, in the lower portion of the Pawtuxet Watershed. Although much of this area is waste land, some is devoted to agriculture, and several thickly settled residential areas and industrial plants are flooded. The residential areas affected are locally known as Natick Flats, Belmont Park, and South Elmwood. Dwellings are mostly of a low-price type with basements subject to frequent flooding by ground water as well as by flood waters of the Pawtuxet River. No serious flooding of highways and bridges results from ordinary floods; highway traffic is but slightly affected and

railroads not at all. A small developed area at Clyde, on the North Branch just above the confluence with the Southwest Branch, is flooded frequently. The principal losses at Clyde are sustained by a large textile finishing plant. Several dwellings, stores, and a lumber yard are also affected.

34. A major flood comparable to the record flood of February 1886 would flood large areas throughout the entire watershed. With the present industrial development of areas adjacent to the river, excessive losses would result. Industrial plants are located at intervals along the main river and particularly on the North and Southwest Branches, where ample fall is available for power. Each mill and adjacent urban development is subject to disastrous inundation by a major flood, although none has occurred in recent years. Main arteries of highway and railroad traffic which cross the watershed would be damaged and travel would be interrupted by a great flood. No loss of life has been recorded from recent floods on the Pawtuxet.

35. The losses which can be assigned a monetary value are classified as follows:

a. Direct losses are the physical damage to property and goods, measured by the present-day cost of repair or the replacement in kind, and the cost of cleanup and moving goods. These have been further subdivided as urban, (including residential, commercial, and public losses), rural, industrial, railroad, and highway.

b. Indirect losses are the value of service or use either lost or made necessary by reason of flood conditions. They include losses of business and wages and similar losses both within and without the flood area during the period of flood and subsequent rehabilitation.

c. Depreciation losses are the abnormal decreases in the value or utility of property beyond that deducible from direct and indirect losses. They have resulted from the floods of March 1936 and July 1938.

36. FLOOD LOSSES PRIOR TO 1936. - Flood accounts in local newspapers stated that cellars were flooded, lowlands were generally inundated, and an occasional mill was forced to shut down, as a result of the storms of March 27-29, 1877; November 3-4, 1927; and November 11, 1932. The flood of October 3-4, 1869, was somewhat more severe. In addition to the usual flooding of the lowlands, a bridge in Coventry was destroyed and railroad traffic was interrupted.

37. The flood of February 1886 was the maximum of record and exceeded the recent flood heights of 1936 and 1938 by as much as eight feet in some localities. A fairly complete picture of the damage caused by this great flood has been reconstructed from newspaper records of the day. Table XI gives a partial record of the losses. It is estimated that the total loss amounted to $250,000, which is equivalent to approximately $675,000 at present price levels. Due to the present development of the basin, should a flood of this magnitude occur today it is estimated that the total loss would amount to $1,250,000, as given by the stage-loss relationship described in Paragraph 41.

(See Table XI on next page)

TABLE XI

DIRECT FLOOD LOSSES - FLOOD OF FEBRUARY 1886

PAWTUXET RIVER WATERSHED

Location	Property	Description of damage	Amount reported
North Branch			
Scituate	Hope Mill	Dam out; mill, machinery, and stock.	$ 35,000
	Highway	Roads and bridges.	25,000
Coventry	Arkwright Dam	Embankment breached.	*
	Highway	Road washout.	1,000
	Village below dam	Flooded to depth of 5 feet.	*
	Interlaken Mills		1,000
	Harris Mills	Dam embankment breached.	2,000
	Pawtuxet Valley Railroad	Undermined below Harris Dam.	*
West Warwick	Birch Hill Bridge	Carried away.	1,000
	Clyde Print Works	Stocks and machinery.	18,000
			83,000
Southwest Branch			
West Warwick	Greene's Works	Riverpoint plant damaged (Bradford Soap Company).	*
	Highway bridge	Riverpoint bridge damaged.	*
Pawtuxet - Main Stem			
West Warwick	B.B.&R. Knight	Natick Dam, mill, machinery, stock.	45,000
	Natick	Barns and small buildings carried away, Natick Hotel damaged, and other "extensive losses."	*
	Railroad bridge	Badly damaged.	*
Warwick	Natick farms	Much poultry carried away.	*
	Highway bridge	Pontiac Bridge wrecked.	*
	Pontiac farms	Badly damaged.	*
	Pontiac Mill	Stock.	18,000
	Pontiac Mill	Machinery and buildings	*
	Kent Corner Dam	Destroyed.	1,000
Cranston	Dye works	Plant destroyed (Imperial Dye Works).	15,000
			79,000
Total			$162,000
Estimated grand total			$250,000

*Not stated.

38. <u>FLOOD LOSSES OF MARCH 1936.</u> - This was one of the more severe floods of recent years. Direct losses total approximately $80,000 as summarized in Table XII. The Lippitt Dam at Phenix on the North Branch and the Marshall Dam on a tributary stream were breached. Farms, nursery crops, and lands were damaged over a wide area in the lower valley. Flooding of cellars and wells at Belmont Park, Natick Flats, and in a few other thickly settled sections, which have no sewage disposal system, created a serious health problem. Three large manufacturing plants sustained damage to buildings and stock, the largest loss occurring on the North Branch at Clyde. A number of other industrial plants were forced to shut down for a few days although they experienced only small losses in this flood. No serious flooding of transportation facilities occurred.

TABLE XII

DIRECT FLOOD LOSSES - FLOOD OF MARCH 1936

PAWTUXET RIVER WATERSHED

By Towns

Town	*Urban	Rural	**Industrial	Highway	Railroad	Totals
Coventry	$ 250	$ 0	$ 1,000	$ 0	0	$ 1,250
Cranston	2,650	5,000	13,000	0	0	20,650
Scituate	100	0	0	0	0	100
Warwick	10,950	500	1,200	500	0	13,150
West Warwick	800	0	43,600	0	0	44,400
Totals	14,750	5,500	58,800	500	0	79,550

By Tributaries

Tributary	*Urban	Rural	**Industrial	Highway	Railroad	Totals
Main Stem	$14,100	$5,500	$ 9,200	$500	0	$29,300
North Branch	400	0	43,500	0	0	43,900
Southwest Branch	250	0	1,100	0	0	1,350
Meshanticut Brook	0	0	5,000	0	0	5,000
Totals	14,750	5,500	58,800	500	0	79,550

*Urban includes residential, commercial, and public losses.

**Industrial and utility.

39. FLOOD LOSSES OF JULY 1938. - The 1938 flood was of approximately the same magnitude as the flood of March 1936 except on the Southwest Branch, where the stage was somewhat lower than in 1936 and losses were small. Direct losses are summarized in Table XIII. They total $148,050, an increase of nearly 100 percent over the losses experienced in March 1936. The increase is partially a result of increased crop losses but principally because emergency sandbagging and pumping at the large plant of The Universal Winding Company was not successful in the July 1938 flood. The largest single loss was sustained by The Universal Winding Company. Lowlands were generally flooded with resulting agricultural damage from destruction of crops and erosion of farm and nursery land. Basements of dwellings were flooded and most manufacturing plants were forced to shut down, although individual losses were not generally large. About two-thirds of the losses occurred on the main stem of the Pawtuxet. At Natick Flats a wide area, including several houses, farms, a nursery, and a large idle mill, was flooded. Residential areas nearby, particularly the Belmont Park and South Elmwood sections, were badly flooded. General pollution of wells constituted a serious health problem. On the North Branch the major losses occurred at Clyde to a large textile printing plant and a lumber yard. Several other mills and dwellings on the North Branch were slightly damaged. Direct losses by towns and by tributaries are shown in Table XIII.

(See Table XIII on next page.)

TABLE XIII

DIRECT FLOOD LOSSES - FLOOD OF JULY 1938

PAWTUXET RIVER WATERSHED

By Towns

Town	*Urban	Rural	**Industrial	Highway	Railroad	Totals
Coventry	$ 150	$ 0	$ 900	$ 0	0	$ 1,050
Cranston	3,100	6,150	65,200	0	0	74,450
Scituate	0	0	200	0	0	200
Warwick	8,750	12,850	750	50	0	22,400
West Warwick	7,150	5,100	37,700	0	0	49,950
Totals	19,150	24,100	104,750	50	0	148,050

By Tributaries

Tributary	*Urban	Rural	**Industrial	Highway	Railroad	Totals
Main Stem	$17,200	$23,950	$ 65,950	$50	0	$107,150
North Branch	1,650	0	38,200	0	0	39,850
Southwest Branch	150	0	600	0	0	750
Pocasset River	150	0	0	0	0	150
Meshanticut Branch	0	150	0	0	0	150
Totals	19,150	24,100	104,750	50	0	148,050

*Urban includes residential, commercial, and public losses.

**Industrial and utility.

40. RECURRING LOSSES. - Preventable recurring losses are those which would occur with future floods, but can be eliminated by flood control works. They are computed from the losses experienced in the March 1936 and July 1938 floods by eliminating losses which are clearly non-recurring by reason of permanently altered usage or abandonment. Recurring losses are segregated into damage reaches in order to provide areas convenient for the summation of losses and the analysis of benefits from various plans of flood protection. The Pawtuxet Watershed was divided into 8 "damage zones" or reaches which were subdivided for local protection studies wherever necessary. The damage zones are described in Table XIV. They were chosen such that individual tributary effects could be readily ascertained, and locations with high concentrations of damage could be segregated. In each damage zone a definite reference gage was available with a good relation between stage and discharge serving as an index to stages throughout the reach. Recurring losses are summarized by damage zones in Table XIV for the flood of July 1938.

(See Table XIV on next page.)

TABLE XIV

PAWTUXET RIVER DAMAGE ZONES AND VALUATION DATA

Damage zone	River	Description	Index station	Real estate valuation 1938 flood area (pre-flood)	Real estate valuation Maximum probable flood area	Real and personal property* Maximum probable flood area	Observed depreciation from 1936 and 1938 floods**	Potential increase of land value
1	North Branch	Kent Dam to 2d NYNH&H Bridge above Junction	Fiskeville Weir	$ 452,000	$ 679,000	$1,079,000	$	$
2	North Branch	2d NYNH&H Bridge above Junction to Junction		254,000	463,000	907,000		
3	Southwest Branch	Flat River Reservoir to Junction	Bradford Soap Company Dam	101,000	735,000	1,224,000		
4	Pawtuxet	Junction (Riverpoint) to Route No. 5 Highway Bridge	Natick Dam	70,000	420,000	500,000		
5	Pawtuxet	Route No. 5 Hwy. Bridge to NYNH&H Bridge 1/4 mile above Elmwood Avenue	Pontiac Dam	174,000	378,000	595,000		40,000
6	Pawtuxet	NYNH&H Bridge 1/4 mile above Elmwood Ave. to Elmwood Ave.		198,000	660,000	2,780,000		18,700
7	Pawtuxet	Elmwood Ave. to Warwick Ave.		245,000	923,000	1,100,000	52,200	110,300
8	Pawtuxet	Warwick Avenue to Mouth		78,000	220,000	253,000	5,000	42,000
Total real estate				1,572,000	4,478,000			
Total real and personal property						8,438,000		
Tax exempt property affected (public and highway)						647,000		
Railroad property affected (approximately)						163,000		
Totals				1,572,000	4,478,000	9,248,000	57,200	211,000

* Land, buildings, inventory, equipment, furnishings, livestock, etc.
** Exclusive of direct and indirect losses.

41. <u>STAGE-LOSS RELATIONSHIP.</u> - The relation between direct loss and stage, referenced to the July 1938 flood crest, was determined for each individual property as the damage surveys progressed. The relation was established for a range in stage extending from the beginning of damage to the level of the maximum probable flood, using the recurring preventable losses of the July 1938 and the March 1936 floods as a control. The individual losses were related to stage at the index station for the reach and summated for one-foot increments of stage. Curves of total direct recurring losses versus stage were prepared for each damage zone.

42. <u>AVERAGE ANNUAL DIRECT LOSSES.</u> - The discharge-frequency curve was plotted for the only U. S. Geological Survey station in the Pawtuxet Watershed, Fiskeville, and was based on recorded and historical floods. The points from this curve were plotted on the general discharge-frequency relationships for the Thames Watershed, showing discharge per square mile versus drainage area in square miles with frequency as a parameter. Since the agreement was excellent and since the Thames and Pawtuxet Watersheds are adjacent and comparable, discharge-frequency curves for index stations for the damage zones in the Pawtuxet Watershed were obtained from the general discharge-frequency relationships for the Thames Watershed. The damage-frequency relationship was obtained for each damage zone from (1) the discharge-frequency relationships, (2) the relationship of damage to stage derived as shown in Paragraph 41, and (3) rating curves. The natural damage-frequency relation was plotted between 100 and 1.0 percent chance. Between 1.0 and 0 percent chance the curve was distorted to the value of the direct loss from one maximum probable flood. The mean ordinate of the entire 100 percent chance period is then the average annual loss. Average annual direct losses are summarized in Table XV. (See Table XV on next page.)

TABLE XV

FLOOD LOSSES BY DAMAGE ZONES

PAWTUXET RIVER BASIN

Damage Zone	River	Recurring direct losses: Flood stage equal to Feb. 1886	Recurring direct losses: Flood stage equal to July 1938	Observed depreciation of real estate: 1936 plus 1938 floods	Average annual losses: Direct	Average annual losses: Indirect	Average annual losses: Depreciation (computed)	Average annual losses: Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	North Branch	$ 40,000	$ 2,250	$ -	$ 3,190	$ 2,297	$ 679	$ 6,166
2	North Branch	320,000	37,500	-	22,680	27,216	370	50,266
3	Southwest Branch	380,000	750	-	9,008	9,548	735	19,291
4	Pawtuxet	111,000	21,900	-	4,802	4,514	420	9,736
5	Pawtuxet	109,000	7,300	-	4,592	4,592	360	9,544
6	Pawtuxet	136,000	60,100	-	7,130	8,556	660	16,346
7	Pawtuxet	100,000	7,300	52,200	6,416	3,336	1,184 (1,305)*	10,936
8	Pawtuxet	54,000	6,550	5,000	2,882	1,210	222 (125)*	4,314
Total		1,250,000	143,560	57,200	60,700	61,269	4,630	126,599

*( ) Estimated from Column (5) at 2-1/2 percent annually.

43. <u>INDIRECT LOSSES</u>. - The indirect losses were computed as a constant percentage of the direct losses. This percentage was determined for each reach by application of empirical ratios to the direct recurring losses of each type and by weighting these as they occurred in the July 1938 flood. The ratios are as follows:

Residential	-	0.40
Commercial	-	0.70
Industrial	-	1.20
Utility	-	1.00
Railroad	-	1.00
Highway	-	1.00
Agricultural	-	0.20
Public	-	0.50

The above ratios have been determined from analysis by sampling methods of the flood losses of 1936 and 1938 in the Pawtuxet River Basin and in other similar areas of the Providence District.

44. <u>DEPRECIATION LOSSES</u>. - The floods of March 1936 and July 1938 have caused substantial depreciation of property values. Recent depreciation is not excessive, however, because existing values and usage already reflect more extreme flood experience. Depreciation losses have been most conservatively estimated at 0.1 percent annually of the value of the property affected. The annual depreciation loss within the damage zones investigated is $4,630, as summarized in Table XV. A great flood such as the maximum predicted flood would cause depreciation losses far in excess of this amount.

45. <u>FLOOD PROTECTION BENEFITS</u>. - The determinable benefits from flood control are derived from the reduction of direct and indirect losses, release from property depreciation, and the enhancement of land values.

Annual direct benefits were computed as the difference in losses between present or natural conditions and conditions as modified by proposed protective works. The modified losses were computed by combining the stage-loss and frequency relations as described in Paragraph 41, except that the modified frequency curve is used in place of the natural frequency. Annual indirect benefits were computed as a percentage of direct benefits by application of the percentage determined for each damage zone as described in Paragraph 43. Depreciation benefits were computed as 0.1 percent annually of the valuation of the property receiving complete protection and were limited to improved private urban areas. A fourth class of benefits incidental to flood control accrues from enhancement in the value of unimproved or partially improved lands. Enhancement has been estimated from the potential land utilization of the protected areas. The annual benefit attributed to protective works is computed as 5 percent of the net increase in land value.

46. ENHANCEMENT BENEFITS. - An increase in land value where development has been retarded by floods is a practical certainty, although the increase may be speculative in nature. In Cranston and Warwick, areas are partially developed with farms, nurseries, and a few scattered low-price dwellings. They are within a few miles of the center of the City of Providence, close to main highways and to adjacent high-type residential and commercial developments. With satisfactory protection from floods, an increase in the value of these unimproved or partially developed lands is certain to occur. Increases from real estate speculation might soon follow approval of the protective works while the more general rise and development would continue over a number of years. The potential increase in land values is conservatively estimated at $211,000 for a net area of commercial frontage and residential development of about 240 acres. Annual benefits are estimated at $10,500 based upon an

report), with a freeboard of 3 feet for the earth levee, and 1 foot for the concrete wall section.

18. Alignment. - The levee protection proposed at Clyde is shown on Plates 3 and 4 of the Appendix. The levee would protect 20 acres of lowland located south of the Pawtuxet Valley branch line of the New York, New Haven and Hartford Railroad. The alignment would begin at the railroad, would follow the tailrace of the Lippitt Mill, and thence would follow the river. At a point 700 feet downstream from Main Street it would diverge from the river to pass around the buildings of the Allied Textile Printers Mill and terminate in the vicinity of Clyde Street at the railroad. The over-all length of the levee would be 3,100 feet. Channel improvements are proposed to rectify restrictions of the channel caused by the levee. The improvement would include the widening of the channel below Main Street Bridge.

19. Geology. - The most prominently developed stratum in the foundation is made up of pervious sand and gravel, averaging about 12 feet in thickness. Throughout about half the length of the proposed levee, the upper portion of the foundation comprises fill materials of cinders, sand, and gravel. Quartzitic rock, which occurs at a depth of from 15 feet to about 25 feet, is directly overlain in places by moderately pervious beds of mixed sand, silt, and gravel.

20. Embankment. - The maximum hydrostatic head to which the earth embankment would be subjected is 15 feet. The section would have a crown width of 10 feet, a riverside slope of 1 vertical on 2-1/2 horizontal and a landside slope of 1 on 2. The embankment would consist of a random section and an impervious blanket on the riverside slope. The random material would be a mixture of gravel, sand, and silt obtained from the foreshore at the lower end of the levee and the blanket material of fine sand and silt obtained within a distance not exceeding one

two most heavily populated and industrialized areas, Cranston and West Warwick, and will result in removal of nearly all objectionable wastes from the main river and its tributary, the Pocasset River. A large measure of sanitation benefit is afforded by flow regulation on the North Branch at the Providence water supply development, and on the Southwest Branch at the Flat River Reservoir dam. An inspection of the stream during the dry season showed a good volume of flow in both major tributaries. No important sources of pollution could be located that are not to be remedied by projects contemplated or in progress. Detailed findings are given in Section I of the Appendix.

51. CONSERVATION. - Additional storage for conservation on the Pawtuxet River is not an important issue at this time. Most water-power installations are obsolete and are being replaced by electric power or by steam plants. The more important use of water is for processing, and the supply is adequate for this purpose.

52. NAVIGATION. - The Pawtuxet River is not commercially navigable in any part of its length. There is no need for navigation on the river. The probability of the development of any need is remote.

53. WILD LIFE. - No improvement in conditions favorable to wild life which can be effected by improvement to the Pawtuxet River has been advocated by local interests.

VII. PLAN OF IMPROVEMENT

54. GENERAL. - Five general methods of flood control in the Pawtuxet Watershed have been studied. These are: (1) possible operation of existing reservoirs to provide a maximum of empty storage capacity for flood control preceding storm seasons, (2) additional reservoir storage, (3) levees or walls, (4) channel improvements, (5) diversion of flood waters.

55. OPERATION OF EXISTING RESERVOIRS. - Flat River and Scituate Reservoirs are the only two reservoirs in the Pawtuxet Watershed which

have an appreciable flood-reducing effect. All other dams either control very small drainage areas or are at run-of-river plants with negligible storage. The capacity of Flat River Reservoir is 2.0 inches on its gross drainage area (see Table V) and its flood-reducing effect is mainly attributable to its surcharge storage. At Scituate Reservoir the normal summer flow is inadequate to supply the draft required for water supply and for the demands of the various mills for water, as stipulated in agreements with individual mills and incorporated in the 1915 Rhode Island Water Act. To ensure a full reservoir by the beginning of the summer period of low run-off, a large portion of the normal winter run-off, including that from snow and ice, must be stored. It is thus possible for a great storm to occur when the reservoir is full, in which case only the surcharge storage is effective. Flood control benefits could be obtained by maintaining the water in Scituate Reservoir at levels below the spillway crest. The reservoir must be kept full, however, especially preceding periods of low run-off, to ensure an adequate volume for water supply and for flowage rights. Some mill owners claim that the economic losses to their mills downstream, should their flowage rights be not maintained, would be greater than the average flood losses. Therefore, it appears that operation of existing reservoirs for flood prevention would not be feasible without defeating the purpose for which they were built.

56. ADDITIONAL RESERVOIR STORAGE - WASHINGTON RESERVOIR. - Only one practicable dam site for flood control storage has been found in the Pawtuxet Watershed. It is located on the Southwest Branch near Washington, and has a drainage area of 61.9 square miles. The reservoir area would include the existing Flat River Reservoir, and would require the abandonment of that reservoir and the maintenance of a conservation pool of equal

capacity behind the Washington Dam. For a storage volume on the drainage area of 61.9 square miles of six inches in excess of the existing capacity of Flat River Reservoir, the Washington Dam would have a spillway crest elevation of 252.5 feet above mean sea level, or 19.9 feet above the existing water surface elevation at the site of the proposed dam. With a maximum surcharge of 10 feet and a freeboard of 5 feet, the height of the top of the dam above the existing water surface would be 34.9 feet. The spillway would be of the solid concrete gravity type, 245 feet long. The outlet structure would consist of an opening in the spillway fitted with two gates having sill elevations at the conservation pool level, 243.7 feet above mean sea level, and with their tops at the same elevation as the spillway crest. Four 3' x 4' sluice gates would be provided at stream bed elevation to draw on the conservation pool, or to empty the reservoir if necessary. The dam would have a total length of 2,500 feet, and would be constructed, aside from the spillway section, of earth embankment. A general plan of the Washington Dam is shown on Plate 2 of the Appendix. In addition, an earth dike 1,650 feet in length would be built across a low saddle in the reservoir rim, to the elevation of the top of the dam. Relocation of 1.73 miles of improved highway and 2.36 miles of single track railroad and the removal of 8 cemeteries having a total of 860 graves, would be necessary. Rehabilitation or purchase of 250 summer camps and cottages would be included in the cost of the flooded area. The annual charges on the estimated total cost of $1,136,000 would be $60,870, which materially exceed the total average annual benefits of $30,970. There are no other feasible reservoir sites, and the benefits to be realized from increasing the storage of any existing reservoir would be less than the charges. The detailed cost estimate of Washington Reservoir is included in Section II of the Appendix.

57. LEVEES. - Levees provide complete protection for the areas encircled. They are usually practicable only for those sections along a river where damages have been concentrated in small areas. These naturally resolve themselves into the more highly industrialized and more densely populated residential areas. On the Pawtuxet, a study of damages suffered in past floods limits such areas susceptible to flood protection by levees to a small area at Clyde, and to that section of the main river extending from just above Elmwood Avenue in Cranston, to the mouth. (See Plate 3.) After a detailed comparison of costs versus benefits, three levee projects were selected for final consideration. These are designated the Clyde, Warwick, and Cranston Levees and are shown on Plates 3 and 5 of the Appendix.

a. Clyde Levee. - At Clyde, a short distance above the junction of the North and Southwest Branches, where the river follows a winding course, the Pawtuxet Valley Railroad crosses the North Branch twice in two-thirds of a mile. The land intercepted between the high railroad embankment and the left bank of the North Branch is the area which would be protected by the Clyde Levee. The levee, with an over-all length of 3,100 feet, would follow the river between the railroad bridges, excluding the tailrace of the Lippitt Mill. It would consist chiefly of an earth embankment with a maximum height of 18 feet, a 10-foot crown width, and slopes of 1 vertical to 2-1/2 horizontal on the riverside, and 1 vertical to 2 horizontal on the landside. Where space limitations would not permit the use of an earth section, reinforced concrete walls of the cantilever type with a maximum height of 13 feet would be used. Abutments for a sandbag closure in time of flood would be provided at Main Street. The channel below the Main Street Bridge would also be improved by widening it to increase the flood discharge capacity. Local drainage would be removed by a pumping plant with a capacity of about 100 cubic feet per second. Costs and benefits for the Clyde Levee are shown in Table XVII.

b. Warwick Levee. - The Warwick Levee would be located on the right bank of the Pawtuxet River, inclosing an area of 40 acres on both sides of Elmwood Avenue in Warwick, including the section known as Belmont Park. The levee would consist mainly of an earth embankment with a maximum height of 20 feet, a crown width of 10 feet, and slopes of 1 vertical to 2-1/2 horizontal on the river side and 1 vertical to 2 horizontal on the land side. In restricted areas near Regnier Pond and Elmwood Avenue, concrete cantilever walls with a maximum height of 18 feet would be used. The height selected for the levee or wall assumes the prior construction of the Broad Street Improvement described in Paragraph 58. The levee would cross Elmwood Avenue by means of a stop-log structure. Local drainage would be removed by a pumping plant with a capacity of about 25 cubic feet per second. Costs and benefits for the Warwick Levee are shown in Table XVII.

c. Cranston Levee. - The Cranston Levee would be located on the left bank of the Pawtuxet River, extending for one-quarter of a mile on each side of Elmwood Avenue. The levee would consist mainly of an earth embankment with a maximum height of 21 feet, a crown width of 10 feet, and slopes of 1 vertical to 2-1/2 horizontal on the river side and 1 vertical to 2 horizontal on the land side. In the restricted space west of Elmwood Avenue, a concrete cantilever wall with a maximum height of 19 feet would be used. The height selected for the levee or wall is predicated upon the assumption that the Broad Street Improvement would have already been constructed. In Scheme 2, described in Paragraph 60, grades are estimated on the assumption that the Warwick Levee is also to be built; in Scheme 3, that the Warwick Levee is not to be built. The levee would cross Elmwood Avenue by means of a stop-log structure. Local drainage would be removed by a pumping plant with a capacity of 75 cubic feet per second. Costs and benefits for the Cranston Levee are shown in Table XVII.

58. <u>CHANNEL IMPROVEMENTS</u>. - The improvements investigated in detail include changes in the Broad Street area at Pawtuxet, designated as the Broad Street Improvement, and two short channel-straightening cuts just downstream from the Elmwood Avenue Bridge, designated as Cranston and Warwick Cut-offs.

a. <u>Broad Street Improvement</u>. - The Broad Street Bridge crosses the Pawtuxet River just above its mouth. A small dam, known as the Broad Street or Pawtuxet Dam, is located 75 feet upstream from this bridge. (See Paragraph 27 b.) The bridge and dam together form a water-stage control for the lower three miles of the Pawtuxet River, the former at high flows and the latter at lower flows. The shift of control from the dam to the bridge occurs with floods equal to those of March 1936 and July 1938. The plan of improvement (see Plate 8 of the Appendix) includes lowering the dam and installing automatic flashboards, adding another span to the bridge, and deepening and widening the channel in the immediate vicinity. The hydraulic effect of this plan in lowering flood stages upstream is shown on Plate 3. Costs and benefits for the Broad Street Improvement are shown in Table XVII.

(1) <u>Dam</u>. - The existing dam is of the ogee concrete overfall type, with a length of 170 feet and a crest elevation 5.2 feet above mean sea level. The plan of improvement calls for lengthening the dam to 230 feet, and lowering the crest elevation to 3.0 feet above mean sea level. Automatic flashboards would be installed on the crest to elevation 5.2 feet, maintaining the present water surface elevations except when the flood of zero damage in the lower three miles of the river is exceeded. With two feet of water over the top of the flashboards, they would trip automatically, lowering the flood stages upstream.

(2) <u>Bridge</u>. - The existing Broad Street Bridge is a twin arch originally of stone masonry construction 30 feet wide. In 1933 the

bridge was widened, using reinforced concrete construction with stone masonry facing. The bridge would be enlarged by adding a third span of equal size, with necessary retaining walls, and with construction similar to that used for widening.

(3) Channel. - The existing channel below the dam would be improved by removing all ledge or other material projecting or lying above an elevation of 3.0 feet below mean sea level.

b. Cranston Cut-off. - The Cranston Cut-off (see Plate 5 of the Appendix) would be a cut 1,600 feet long across a neck of land on the left side of the existing channel, starting 2,200 feet below the Elmwood Avenue Bridge. It would utilize, for most of its length, a swale which is apparently a former channel of the river. Backwater studies disclosed that the cut-off would lower flood stages from its upper end to the Pettaconsett Dam 1-1/2 miles above Elmwood Avenue. At Elmwood Avenue, the stage of the maximum predicted flood would be lowered 0.75 foot by this plan, assuming that the Broad Street Improvement will already have been made, and the stage of a flood equal to that of July 1938 would be lowered 0.6 foot. The cost and benefits for the Cranston Cut-off are shown in Table XVII.

c. Warwick Cut-off. - The Warwick Cut-off would be a cut 1,500 feet long starting immediately below the Elmwood Avenue Bridge, and crossing the section known as Belmont Park. This cut-off would provide smaller reductions in upstream flood stages than the Cranston Cut-off. The cost of excavation would be at least as large as those for the Cranston Cut-off, and land damages would be much greater. Also, it would provide protection for a smaller area than the Cranston Cut-off, since the latter starts farther downstream. Because of the stream alignment, it is not feasible to construct both cut-offs, and hence the Warwick Cut-off was not considered further.

59. DIVERSION OF FLOOD WATERS - PONTIAC DIVERSION. - A plan has been studied for the diversion of flood waters from the main river to Greenwich

Bay. Such a plan would completely control the flow from 195 square miles of the total of 230.4 square miles of drainage area in the Pawtuxet Watershed, and, except for the rare occurrence of an extremely high tide such as that of September 21, 1938, would provide virtually complete protection from floods for all sections of the main river from Pontiac to the mouth. It is thus attractive as an engineering solution for flood control and would be a substitute for the Cranston and Warwick Levees, the Cranston Cut-off, and the Broad Street Improvement. The logical point for this diversion is from just below the mouth of Meshanticut Brook at Pontiac to Apponaug Cove at Apponaug. During periods of normal river flow, all the discharge would be passed through gates in the diversion dam, and flow conditions would remain as at present. During flood periods, the entire flow would be diverted through a channel to Apponaug Cove. The plan would require a diversion dam with gates, and a channel with a gate structure, and other appurtenant structures (see Plate 10 of the Appendix). The hydraulic requirements for the diversion dam, the gates, and the diversion channel are discussed in Paragraph 64, Section II of the Appendix. Costs and benefits for the Pontiac Diversion are shown in Table XVII.

a. Diversion dam. - The diversion dam across the Pawtuxet River would be located just west of the highway bridge at Pontiac. It would have an over-all length of 1,900 feet and would be of rolled earth fill construction with a crest elevation of 46.0 feet above mean sea level, which is approximately 25 feet above the bed of the stream. The top width would be 20 feet, with side slopes of 1 vertical to 3 horizontal. A gate section consisting of three Stoney-type gates, each about 15 feet wide by about 8.5 feet high, would be located in the dam near the existing channel to discharge the normal flow of the stream. The sill elevation of these gates would be at an elevation 23.0 feet above mean sea level.

b. Diversion channel. - The channel would have an over-all length from the river to Apponaug Cove of 5,500 feet. The upper 4,200 feet would be lined with concrete and would have a bottom width of 100 feet, and side slopes of 1 vertical to 1-1/4 horizontal up to 3 feet above maximum water surface. At this elevation there would be a 10-foot berm, and above this the slope would be 1 vertical to 1-1/2 horizontal up to natural ground surface. The lower 1,300 feet of the channel would be concrete-lined, and would have a bottom width of 50 feet with side slopes of 1 vertical to 1 horizontal up to 4 feet above the maximum water surface. The entrance to the channel would be a reinforced concrete gate structure 140 feet long with a sill elevation of 21.4 feet above mean sea level. It would be equipped with eight Stoney-type gates, each about 15 feet wide by 8.5 feet high. These gates would be shut in times of normal flow, excluding the water from the diversion channel. In times of flood the gates in the diversion dam would be closed and the gates to the diversion channel would be open, diverting the flood waters through the channel.

c. Appurtenances. - Three new highway bridges crossing the diversion channel would be necessary, at East Avenue and at Highways Nos. 117 and 1. Levees would also be required to confine the flow in the channel at a pond near the Apponaug Mill. Normal operation of this pond would be maintained by the installation of gates.

60. PLANS STUDIED. - The various plans for flood protection which have been studied have been combined into four composite schemes for economic comparison, as stated below. The Clyde Levee is included in all schemes.

a. Scheme 1. - Scheme 1 includes the Clyde Levee and the Pontiac Diversion. The Clyde Levee provides complete protection for a small area on the left bank at Clyde. The Pontiac Diversion provides virtually complete protection for the lower five miles of the Pawtuxet River, i.e., damage zones 5, 6, 7, and 8. Scheme 1 is a prior alternative to any of the other schemes.

b. Scheme 2. - Scheme 2 includes the Broad Street Improvement and the Clyde, Cranston, and Warwick Levees. The Broad Street Improvement provides a measure of protection for the lower 3 miles of the Pawtuxet River, i.e., damage zones 6, 7, and 8, by lower flood stages. The three levees provide complete protection against a maximum predicted flood for the areas concerned.

c. Scheme 3. - Scheme 3 includes the Broad Street Improvement and the Clyde and Cranston Levees. It is the same as Scheme 2 minus the Warwick Levee.

d. Scheme 4. - Scheme 4 includes the Broad Street Improvement, Clyde Levee, and the Cranston Cut-off. The Warwick and Cranston Levees are omitted.

61. COSTS AND BENEFITS. - The costs of all the works, except the Pontiac Diversion Channel, are based on the requirements that local interests provide, without cost to the United States, all lands, easements, and rights-of-way necessary for the construction of a project; hold the United States free from damages due to the construction; and maintain and operate all works after completion. The costs of the Pontiac Diversion are based on the requirement that local interests contribute 25 percent of the total cost of the Pontiac Diversion Channel, not to exceed $347,500, including the costs of lands, easements, and rights-of-way (see Paragraph 70). In each case, the costs of pumping plants are included as Federal costs and the cost of intercepting sewers is included as local cost. A summary of the costs for the four schemes is shown in Table XVI. The detailed costs are evaluated in Section II of the Appendix. The average annual benefits are listed and compared with the annual costs for each scheme in Table XVII.

TABLE XVI

SUMMARY OF COSTS

Plan of improvement	Construction	Bridge	Pumping plants	Drainage	Lands and damages	Total	Cost to United States(1) Total	Cost to United States(1) Annual	Cost to local interests (1) Total	Cost to local interests (1) Annual	Total annual cost(1)
SCHEME 1											
Pontiac Diversion	1,082,000	229,000	-	-	79,000	1,390,000	1,042,500(2)	50,010	347,500(2)	33,940	83,950
Clyde Levee	194,000	-	83,000	-	22,000	299,000	277,000	14,100	22,000	4,210	18,310
Total	1,276,000	229,000	83,000	-	101,000	1,689,000	1,319,500	64,110	369,500	38,150	102,260
SCHEME 2											
Clyde Levee	194,000	-	83,000	-	22,000	299,000	277,000	14,100	22,000	4,210	18,310
Cranston Levee	243,000	-	87,000	42,000	30,000	402,000	330,000	16,480	72,000	7,120	23,600
Warwick Levee	235,000	-	34,000	11,000	34,000	314,000	269,000	12,420	45,000	4,680	17,100
Broad Street Improvement	52,000	47,000	-	-	5,000	104,000	99,000	5,790	5,000	270	6,060
Total	724,000	47,000	204,000	53,000	91,000	1,119,000	975,000	48,790	144,000	16,280	65,070
SCHEME 3											
Clyde Levee	194,000	-	83,000	-	22,000	299,000	277,000	14,100	22,000	4,210	18,310
Cranston Levee	178,000	-	87,000	42,000	29,000	336,000	265,000	13,700	71,000	6,710	20,410
Broad Street Improvement	52,000	47,000	-	-	5,000	104,000	99,000	5,790	5,000	270	6,060
Total	424,000	47,000	170,000	42,000	56,000	739,000	641,000	33,590	98,000	11,190	44,780
SCHEME 4											
Clyde Levee	194,000	-	83,000	-	22,000	299,000	277,000	14,100	22,000	4,210	18,310
Broad Street Improvement	52,000	47,000	-	-	5,000	104,000	99,000	5,790	5,000	270	6,060
Cranston Cut-off	55,000	-	-	-	20,000	75,000	55,000	2,890	20,280	1,410	4,300
Total	301,000	47,000	83,000	-	47,000	478,000	431,000	22,780	47,280	5,890	28,670

(1) Note: Local interests providing lands, damages, and maintenance.

(2) Note: Local interests contributing 25 percent of the total cost.

TABLE XVII

AVERAGE ANNUAL BENEFITS AND COSTS

Scheme	Damage zone	Average annual benefits: Direct	Indirect	Depreciation	Enhancement	Total	Total annual cost (1)	Total annual cost to Federal Government (1)	Ratio average annual benefit to annual cost: Federal	Total
SCHEME 1										
Pontiac Diversion	5	4,370	4,370	180	2,000					
	6	7,090	8,510	540	900					
	7	6,320	3,280	740	5,500					
	8	2,800	1,180	140	2,100					
Subtotal		20,580	17,340	1,600	10,500	50,020	83,950(2)	50,010(2)	1.00	0.60
Clyde Levee		22,320	26,780	260		49,360	18,310	14,100	3.50	2.70
Total		42,900	44,120	1,860	10,500	99,380	102,260	64,110(2)		
SCHEME 2										
Clyde Levee		22,320	26,780	260		49,360	18,310	14,100	3.50	2.70
Cranston Levee		5,880	6,600	700	200	13,380	23,600	16,480	)	
Warwick Levee		1,540	750	160	500	2,950	17,100	12,420	) 0.74	0.55
Broad Street Improvement		5,260	3,790	280		9,330	6,060	5,790	)	
Total		35,000	37,920	1,400	700	75,020	65,070	48,790		
SCHEME 3										
Clyde Levee		22,320	26,780	260		49,360	18,310	14,100	3.50	2.70
Cranston Levee		6,110	6,720	680	200	13,710	20,410	13,700	) 1.19	0.88
Broad Street Improvement		5,470	3,870	280		9,620	6,060	5,790	)	
Total		33,900	37,370	1,220	200	72,690	44,780	35,590		
SCHEME 4										
Clyde Levee		22,320	26,780	260		49,360	18,310	14,100	3.50	2.70
Broad Street Improvement		6,290	4,650	370		11,310	6,060	5,790	) 1.70	1.42
Cranston Cut-off		1,730	1,710	10		3,450	4,300	2,890	)	
Total		30,340	33,140	640		64,120	28,670	22,780		

(1) Note: Local interests providing lands, damages, and maintenance.

(2) Note: Local interests contributing 25 percent of the total cost.

VIII. DISCUSSION

62. CLYDE LEVEE. - Scrutiny of the average annual losses on the North Branch discloses large losses concentrated in a small area on the left bank at Clyde. Diversion of flood waters from above this locality is not feasible, and channel improvements will not appreciably reduce the losses. It has already been shown that control of existing reservoirs on the North Branch cannot be depended upon for flood control, and that there are no new sites suitable for flood control storage. Large localized losses fully justify a levee or wall at this location. The average annual losses suffered within the area encircled by the proposed Clyde Levee amount to $49,360, which is more than adequate to justify the annual charges of $18,310 on the total cost of $299,000 necessary to build and maintain the levee. The area that would be protected includes a factory, a lumber yard, and several business blocks and homes. The factory concerned furnishes employment to five hundred persons, and the economic welfare of Clyde is almost entirely dependent upon it. It is considered to be in good financial condition, and gives promise of continuing indefinitely. As an indication of its stability, its operation has been practically continuous at least since 1886. With the protection which would be furnished by the Clyde Levee benefits would extend beyond the limits of the small area encircled through the wage security of the persons employed in the area.

63. WARWICK LEVEE. - This levee provides flood protection to that residential section of Warwick known as Belmont Park, and some mercantile establishments along Elmwood Avenue. Protection is urgently desired by the residents of Belmont Park. During floods of the magnitude of the 1936 and 1938 floods, it is necessary to evacuate the area completely. Flooding of cellars is an annual occurrence. For this reason, Belmont Park is not a first-class residential area. A levee which would furnish

complete protection for it would be practically a ring levee. It would be of such a height as to occupy a large proportion of the area requiring protection. It would also so restrict the natural flood plain of the river as to increase flood heights in Cranston and upstream by as much as 5 feet for the maximum predicted flood. The levee would cross Elmwood Avenue, a main thoroughfare from Providence south, with a stop-log structure. Its closure would cause an interruption to traffic during floods. Some form of protection other than levees is preferable for this area. The cost for a levee to protect the area, and the benefits therefrom combined in various schemes with other plans, are shown in Table XVII.

64. CRANSTON LEVEE. - The Cranston Levee would furnish complete protection to an area of concentrated and large flood losses on the left bank of the main river on both sides of Elmwood Avenue in Cranston. The area includes one large factory, a school, business blocks, and several homes. The factory involved is a prosperous concern furnishing steady employment to 650 persons. Complete protection for this factory and consequent insurance against payroll interruptions would provide economic benefits to a considerably larger area than that inclosed by this levee. This levee would not materially increase flood stages in Warwick or upstream. The levee would cross Elmwood Avenue with a stop-log structure of a height dependent upon the prior or simultaneous construction of Warwick Levee or the Broad Street Improvement. As in the case of the Warwick Levee, this stop-log structure would cause an interruption to traffic during floods. The costs and the benefits allocated to the Cranston Levee under various schemes are shown in Table XVII. An area adjacent to the lower end of the levee suffers large flood losses but not sufficiently large to justify extending the levee to include this area.

65. <u>BROAD STREET IMPROVEMENT</u>. - This plan would involve a change in conditions in the vicinity of Broad Street resulting in a lowering of the stage control affecting the lower three miles of the river. As a flood protection project, it would have the advantage of furnishing limited protection to the entire lower Pawtuxet, whereas any one levee plan, such as the Warwick or Cranston Levee, would furnish complete protection to a limited area only. Thus, the Broad Street Improvement would provide a measure of flood protection for scattered areas without sufficiently concentrated losses to justify a levee project. This plan is combined with either or both of the Warwick and Cranston Levees, since it lowers the grade and cost of the levees. It would in no way interfere with recreational facilities on the lower Pawtuxet, as present stages would be maintained except for flood stages of two feet or greater over the existing Pawtuxet Dam, when the automatic flashboards would go out. Such flood stages occur on an average of once a year. The total cost for the construction of the Broad Street Improvement would be $104,000, with annual charges of $6,060, and the average annual benefits would be $12,100 if not considered in conjunction with the Cranston or Warwick Levee. The allocation of average annual benefits to this improvement in schemes including the levees is shown in Table XVII.

66. <u>CRANSTON CUT-OFF</u>. - The Cranston Cut-off would provide a reduction in flood stage upstream by shortening the existing channel with a new channel across a neck of land below Elmwood Avenue. The reduction of stage was found to be greatest when this plan was considered with the Broad Street Improvement. Since the cut-off would be dependent upon the Broad Street Improvement to obtain the maximum reduction in stage, it was included in Scheme 4. The cut-off would provide partial protection to upstream areas which also receive partial protection from the Broad Street Improvement. This plan could also have been combined

with the Warwick and Cranston Levees but the reduction in cost due to the lowering of the levees would not justify the necessary expenditure. The total cost of construction for the Cranston Cut-off would be $75,000 with annual charges of $4,300. The annual benefits would be $3,450 in conjunction with the Broad Street Improvement. The allocation of average annual benefits to the Cranston Cut-off in Scheme 4 is shown in Table XVII.

67. PONTIAC DIVERSION. - The Pontiac Diversion as proposed would divert all flood waters from the main stream above Pontiac. During normal flow periods, the diversion channel would remain dry and the entire flow would follow the present course of the river. Consequently, no water rights would be infringed, and no interference would result to recreational facilities on the lower Pawtuxet. The Pontiac Diversion would furnish virtually complete protection for the lower six miles of the river, while the Warwick and Cranston Levees would furnish complete protection for only limited areas, and the Broad Street Improvement would furnish partial protection for the lower three miles of the river. The adoption of the diversion plan would obviate any necessity for the Warwick and Cranston Levees and the Broad Street Improvement, since it would provide complete protection to the areas which they would benefit. In addition, the diversion would provide desirable protection to the area adjacent to the lower end of the Cranston Levee site that could not justifiably be included in the area encircled by the Cranston Levee. It would protect Belmont Park without occupying part of the area as would be the case with a levee. There would be no necessity for stop-log structures across Elmwood Avenue with their attendant psychological disadvantages, operation requirements, and interruptions to traffic. It would eliminate the danger of payroll interruptions from floods in the entire protected

area, with resulting benefits extending to entire communities beyond the sections along the river. Pontiac would be completely protected, as well as all other sections along the river above the Old Pettaconsett Dam, where the effect of the Broad Street Improvement would end. It is the best engineering solution to the flood control problem on the lower Pawtuxet River. The Rhode Island State Bureau of Fisheries has stated that the passage of large quantities of fresh water into Narragansett Bay via Apponaug Cove and Greenwich Bay would cause no damage to local shell-fishing interests. The occasional use of the diversion canal for flood control would reduce the polluted areas in Apponaug Cove and Greenwich Bay, resulting in a benefit to the adjacent localities.

68. UNEVALUATED BENEFITS. - Losses previously discussed and used to compute the average annual benefits have been those easily expressed in dollars and cents. There are additional benefits which have not been evaluated. No estimate has been made of the increase in annual direct losses which will result from the normal growth and development that may be reasonably anticipated even if flood protection is not provided. The cities of Cranston and Warwick, wherein protection is advocated, are growing suburbs of the City of Providence. They have shown increases in population of 30 percent in the last decade, and a substantial increase in direct benefits from the flood control measures advocated is anticipated during the assumed 50-year economic life of the protective works. The enhancement benefits previously claimed were based only upon benefits accruing from increase in land value. Additional benefits will result from the increase in population and the building developments made feasible by protection of the flood areas. Additional benefits will result also from the prevention of innumerable other losses which are not susceptible of direct monetary evaluation. They include serious adverse effects on the lives and security of the people and communities concerned - potential loss of life, mental and physical strain, hardship, inconvenience,

and impairment of public health. Pollution of wells by flood waters presents a serious problem even in minor freshets. In the Pawtuxet Valley these elements of flood experience and apprehension, which may not be evaluated, determine the utilization, desirability, and future growth of the area, and form an additional justification for protective works.

69. ATTITUDE OF LOCAL INTERESTS. - The Director of Public Works of the State of Rhode Island and the officials of the towns and cities affected were consulted to determine the willingness of local committees to cooperate in the various schemes considered. The consensus of opinion was that Scheme 1, consisting of the Pontiac Diversion and the Clyde Levee, would provide protection to the greatest possible area and would result in the greatest flood control benefits to all interests concerned. It was stated that cooperation to a reasonable degree, in proportion to the financial ability of the communities, might be expected. A special committee was appointed by the Rhode Island General Assembly to consider flood problems in the Pawtuxet Valley. This committee has recommended to the General Assembly that steps be taken to enable the issuance of bonds to an amount not exceeding $350,000, and that the proceeds be available for local participation if the Federal Government will construct the Pontiac Diversion Channel.

IX. CONCLUSIONS

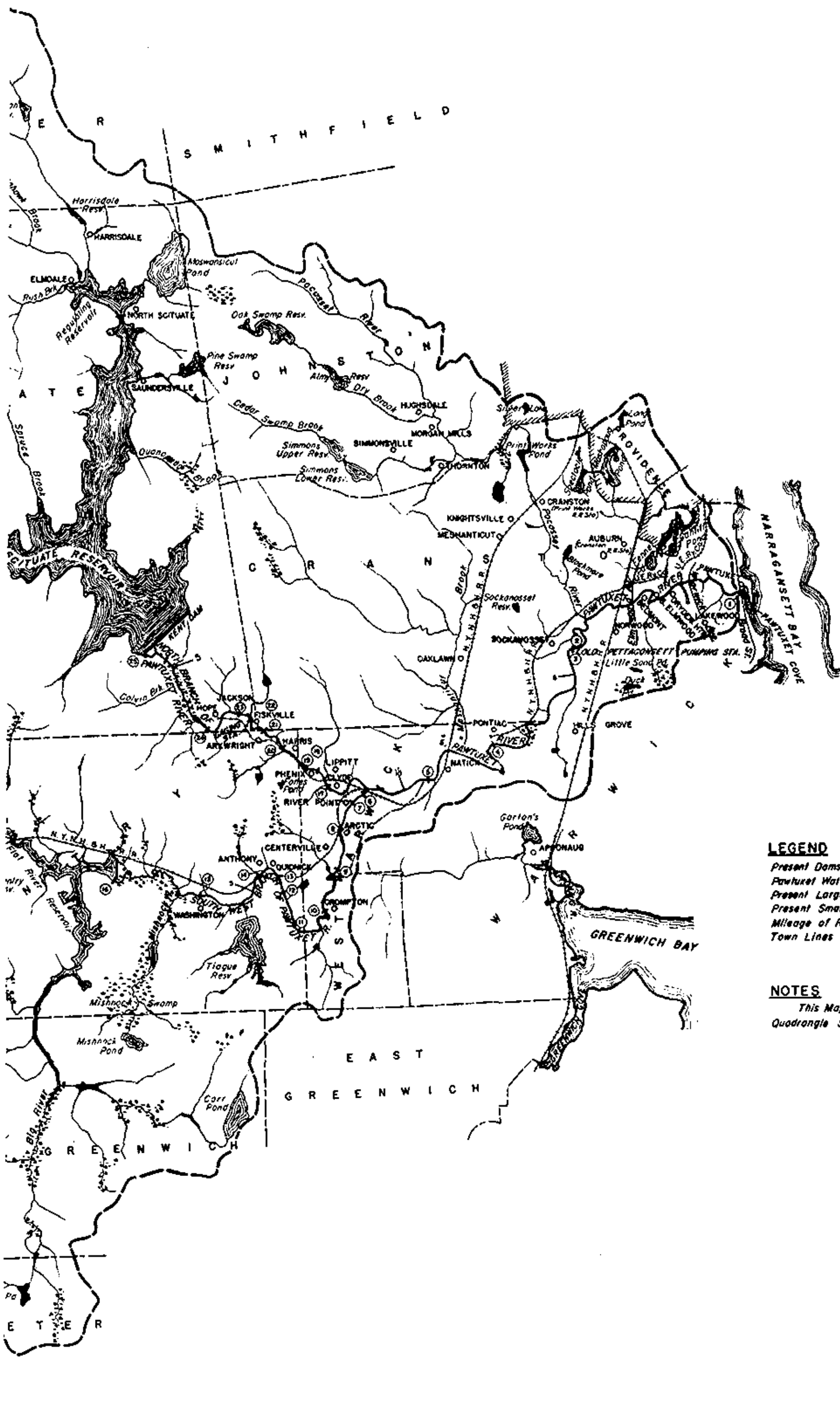
70. Scheme 1, including the Pontiac Diversion and the Clyde Levee, offers the best justifiable solution of flood problems on the Pawtuxet River. As shown in Table XVII, the annual benefits of each component of this scheme are greater than the annual costs to the Federal Government. For the Pontiac Diversion Channel the computed benefits, and also the unevaluated benefits, are such as to justify participation by local interests in the costs of the improvement. A contribution of 25 percent of the estimated total capital cost, not to exceed $347,500, including the cost of lands, easements, and rights-of-way, is considered a fair share for this participation. It is to the interest of the Federal Government to participate in a flood control program for the Pawtuxet River substantially in accordance with Scheme 1,

provided that local interests hold and save the United States free from damages; give assurance that they maintain and operate the works when finished; furnish lands, easements, and rights-of-way; and, in the case of the Pontiac Diversion Channel, make a contribution not to exceed $347,500, which will include the cost of lands, easements, and rights-of-way. In lieu of the contribution of $347,500 for the Pontiac Diversion Channel, local interests should be permitted to provide the lands, easements, and rights-of-way, at an estimated cost of $79,000, build the necessary bridges for the Pontiac Diversion Channel at an estimated cost of $229,000, and make a cash contribution not to exceed $39,500.

X. RECOMMENDATIONS

71. It is recommended that a flood control plan for the Pawtuxet River be adopted consisting of local protective works at Clyde, Rhode Island, and a diversion channel from Pontiac to Apponaug Cove, all at an approximate estimated cost of $1,689,000 of which $1,319,500 is the approximate estimated cost to the United States for construction. It is further recommended that no Federal funds be expended upon the proposed plan until local interests give assurance that they will hold and save the United States free from damages due to the construction works; that they will maintain and operate all the works after completion in accordance with regulations prescribed by the Secretary of War; that they will provide the necessary lands, easements, and rights-of-way for the Clyde Levee at an estimated cost of $22,000; and that they will contribute 25 percent of the total capital cost of the Pontiac Diversion Channel, not to exceed $347,500, including the cost of lands, easements, and rights-of-way, or, in lieu thereof, provide lands, easements, and rights-of-way, at an estimated cost of $79,000, concurrently construct the bridges over the diversion channel, at an estimated cost of $229,000, and make a cash contribution not to exceed $39,500. If authorized, allotment for the work should be made in one sum to secure economical prosecution of the work.

J. S. Bragdon
Lieut. Col., Corps of Engineers
District Engineer



LEGEND

Present Dams shown thus
Pawtuxet Watershed Boundaries shown thus
Present Large Reservoirs, Lakes, and Ponds
Present Small Reservoirs, Lakes, and Ponds
Mileage of River shown thus — 15
Town Lines shown thus

NOTES

This Map reproduced from U.S. Geological Survey Quadrangle Sheets.

PAWTUXET RIVER FLOOD CONTROL

PAWTUXET RIVER

MAP OF WATERSHED

PAWTUXET RIVER — RHODE ISLAND

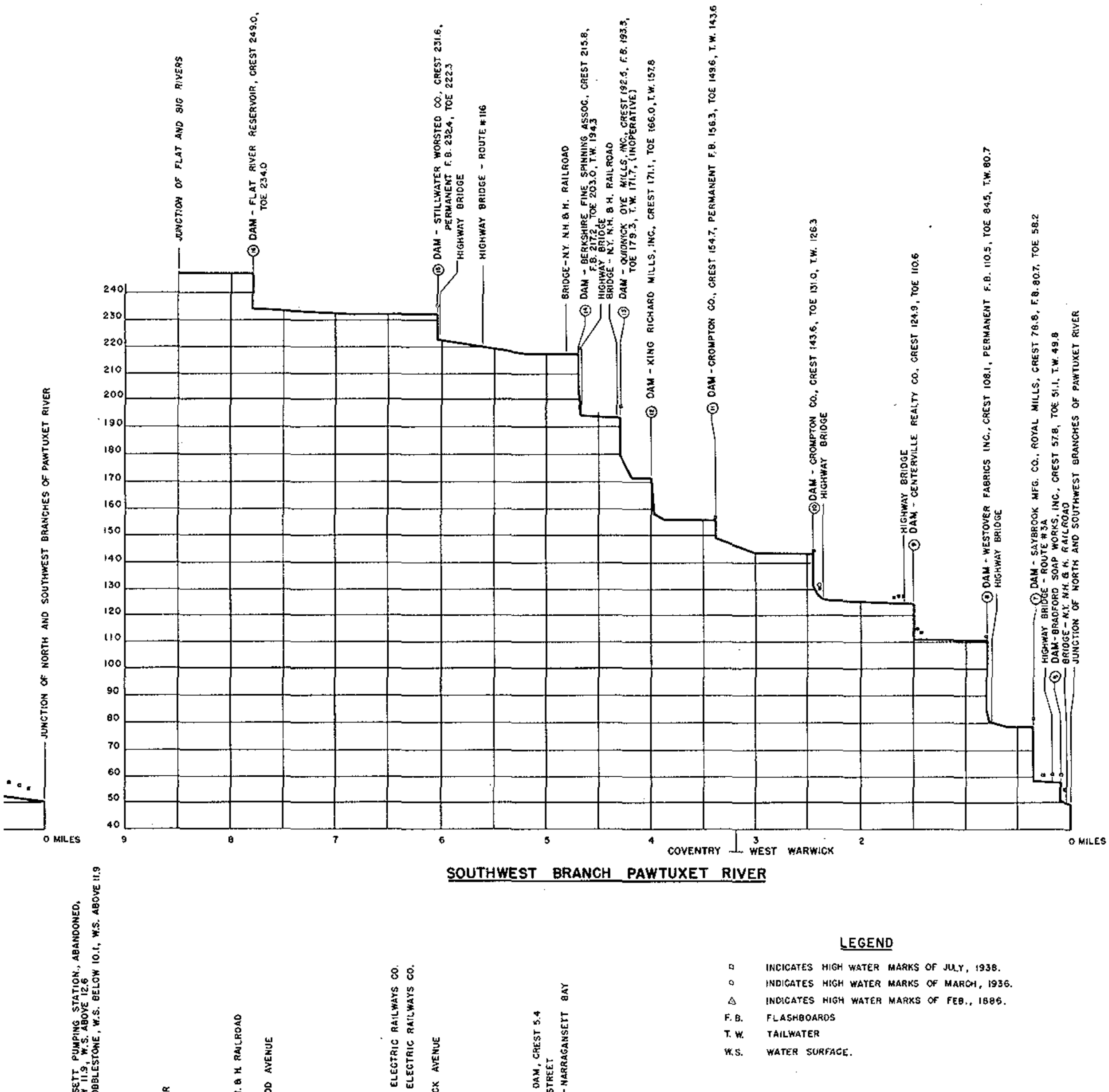
IN 1 SHEETS — SCALE 1 0 2 MI — SHEET NO. 1

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT. 1939

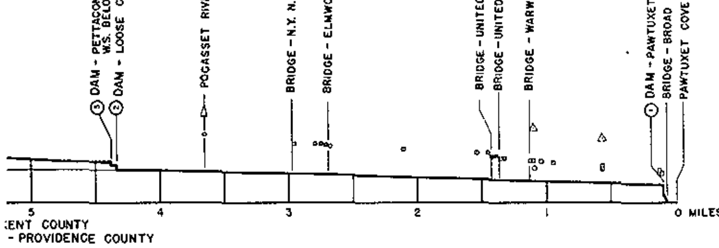
SUBMITTED	APPROVAL RECOMMENDED	APPROVED
ENGINEER, HEAD HYDRAULICS SECTION	PRINCIPAL ENGINEER, CHIEF F. C. ENGINEERING DIV.	LT. COL. CORPS OF ENGINEERS, DISTRICT ENGINEER

COMPILED		
ASST. ENGINEER	DRAWN BY O.C. TRACED BY O.C. CHECKED BY	FILE NO. PT-3-1001 TO ACCOMPANY REPORT DATED: OCT. 20, 1939

CORPS OF ENGINEERS, U. S. ARMY



SOUTHWEST BRANCH PAWTUXET RIVER



ENT COUNTY
- PROVIDENCE COUNTY

IVER

LEGEND

□	INDICATES HIGH WATER MARKS OF JULY, 1938.
○	INDICATES HIGH WATER MARKS OF MARCH, 1936.
△	INDICATES HIGH WATER MARKS OF FEB., 1886.
F. B.	FLASHBOARDS
T. W.	TAILWATER
W.S.	WATER SURFACE.

NOTE:
ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL DATUM.

PAWTUXET RIVER FLOOD CONTROL

PAWTUXET RIVER

PROFILES

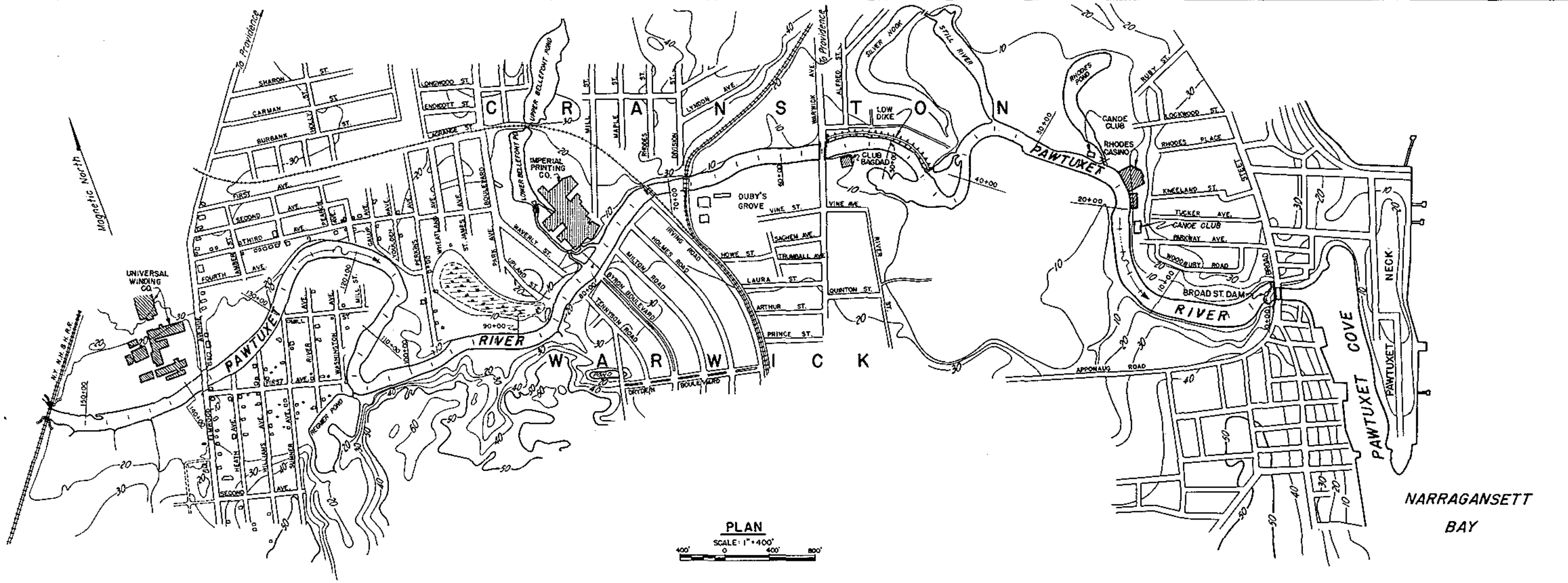
PAWTUXET RIVER — RHODE ISLAND

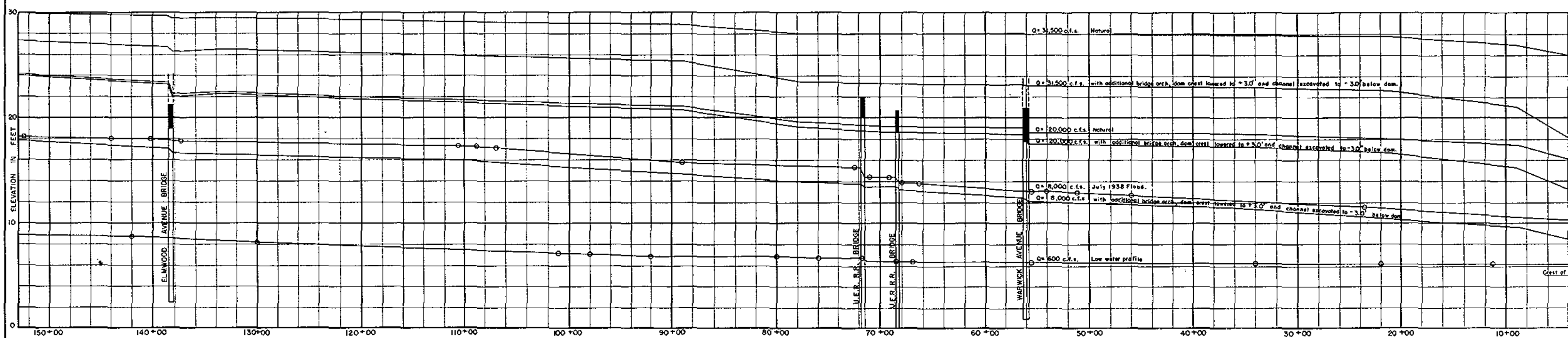
IN 1 SHEETS — SCALE AS SHOWN — SHEET NO. 1

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT. 1939

SUBMITTED:	APPROVAL RECOMMENDED:	APPROVED:
John B. Dricko, ENGINEER, HEAD, HYDRAULICS SECTION	J. S. Burns, PRINCIPAL ENGINEER, CHIEF, F. C. ENGINEERING DIV.	J. S. Bragdon, COL. CORPS OF ENGINEERS, DISTRICT ENGINEER
COMPILED: Herbert C. Duke, ASST. ENGINEER	DRAWN: DC; TRACED: D.C. & J.A.C.; CHECKED: H.C.D.	FILE NO. PT-3-1002 TO ACCOMPANY REPORT DATED: OCT. 20, 1939

PLATE 2





DISTANCE IN FEET ABOVE UPSTREAM SIDE OF BROAD STREET BRIDGE

SCALE: HOR. 1" = 400'
VERT. 1" = 4'

MAP COMPILED FROM ORIGINAL SURVEYS BY THE FOLLOWING AGENCIES

1. U.S. Engineer Office, Providence, R.I.
2. R.I. Division of Rivers and Harbors; By U.S. Works Progress Administration.
3. U.S. Geological Survey topographic sheets.

NOTE

Elevations refer to Mean Sea Level Datum.

For high floods, it was assumed that the U.E.R. R.R. bridges (trestles) were washed away.

Lower bridge losses are shown for higher discharges at Warwick Ave. and Elmwood Ave. because of increased discharge over bridge approaches.

Observed water surface profiles indicated by circles —o—

PAWTUXET RIVER FLOOD CON

PLAN AND PROFILE

FROM MOUTH TO ELMWOOD A

PAWTUXET RIVER RHODE I

IN 1 SHEET SCALE AS SHOWN SHEET

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT.

SUBMITTED: ENGINEER, HEAD, HYDRAULIC SECTION

APPROVAL RECOMMENDED: J. S. Burns, PRINCIPAL ENGINEER, CHIEF, F. C. ENGINEERING DIV.

APPROVED:

COMPILED: ASST. ENGINEER

DRAWN: H.A.S.
TRACED: G.F.S.
CHECKED

FILE NO. PT-3
TO ACCOMPANY RE
DATED: OCT 20, 193

REPORT ON SURVEY FOR FLOOD CONTROL

ON THE

PAWTUXET RIVER, RHODE ISLAND

UNITED STATES ENGINEER OFFICE

PROVIDENCE, RHODE ISLAND

APPENDIX

SECTION I - POLLUTION

SECTION II - DETAILED ESTIMATES AND COSTS

APPENDIX TO THE REPORT

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SECTION II. DETAILED ESTIMATES AND COSTS

GENERAL

WASHINGTON RESERVOIR

CLYDE LEVEE

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SECTION II. DETAILED ESTIMATES AND COSTS

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SECTION II. DETAILED ESTIMATES AND COSTS

SECTION I - POLLUTION

1. General. - Stream pollution has not been a major problem in the Pawtuxet River Watershed. It will be of minor importance upon completion in 1942 of improvements now in progress. Two sewer systems with adequate treatment plants are now being built, and will serve the two most heavily populated and industrialized areas, resulting in removal of nearly all objectionable wastes from the main river and its principal tributary, the Pocasset River.

2. Scope. - This section of the Appendix describes existing sources, types, and amounts of polluting substances; general conditions along the various streams of the basin; and remedial measures, underway and proposed. A detailed field inspection was made during September 1939 when flows approximated the annual low. The air temperature during the inspection period averaged 70 degrees Fahrenheit, sufficiently high to reveal any malodorous conditions. Studies were also made of reports prepared by other agencies, particularly those of the Rhode Island Board of Purification of Waters, and of plans for sewerage systems and sewage treatment plants being constructed in Cranston and West Warwick.

3. Previous reports. - In 1924 the Board of Purification of Waters included in their biennial report results of sanitary surveys of the Pawtuxet and Pocasset Rivers made during 1923. Descriptions given in these reports,* available at the Board offices, were found to be indicative of present conditions. Although the population of the watershed has increased in the intervening years, decrease in industrial activity has offset added domestic sewage volumes. Significant improvement in

* "Report of Investigations of the Pollution of Certain Rhode Island Public Waters during 1923 and 1924, Presented to the Board of Purification of Waters," by the late Stephen DeM. Gage, Sanitary Engineer, and Philip C. McGouldrick, Chemist of the Board.

low-water flow also resulted when Scituate Reservoir for Providence water supply began operation in 1926. Minimum flow provisions of the act authorizing this development are discussed in Paragraph 13 and Table II of this section of the Appendix.

4. Pollution laws.

a. Federal. - The Pawtuxet River, while not a navigable waterway, is tributary to Narragansett Bay and is therefore subject to certain of the provisions of the "Laws for the Protection and Preservation of the Navigable Waters of the United States" as embodied in the River and Harbor Act approved March 3, 1899. Public Document No. 238, 68th Congress, 1st Session, the "Oil Pollution Act of 1924," deals specifically with deposition of oil, primarily with regard to coastal navigable waters.

b. State. - Chapter 125 of the General Laws, State of Rhode Island, Revision of 1923, amended by Public Laws 1935, Chapter 2250, entitled "Of the Pollution of the Waters of the State" describes operation of pollution control measures for inland waters, including the Pawtuxet River and its tributaries. The Division of Purification of Waters is empowered to investigate, regulate or prohibit the pollution of the State's waters. "The term 'pollution' shall be held to mean the entrance or discharge of sewage . . . in such quantity as to cause or be likely to cause either by itself or in connection with other sewage so discharged, damage to the public, or to any persons having a right to use said waters for boating, fishing or other purposes, or owning property in, under or bordering upon the same." Section 5 states that "If any person is polluting the waters of the state, and if after investigation the division shall so find . . . (it) may enter an order directing such person to adopt or use or to operate properly some practicable and reasonably available system to prevent such pollution, having due regard for the rights and interests of all persons concerned." The order may specify the particular system or means to be used, and shall specify the time within which such system or means must be in operation. Penalties for violations are such that each month in which an order is unheeded may constitute a separate count.

5. Description of Pawtuxet Basin. - See Paragraphs 8 to 11 of main report, preceding, for location and size, topography, and description of the main stream and its tributaries. Paragraph 13, "Population," indicates that about 77 percent of the population is concentrated in Cranston and West Warwick, and that other communities are individually small and scattered throughout the river valleys. Other than the urban areas, near the mouth of the river and adjoining Providence, population centers about numerous mill communities of small area. The sections inland from the more important river branches are very sparsely populated because of lack of good farming lands.

6. Domestic sewage. - The 3.3 square miles of Providence which lie within the Pawtuxet drainage basin are served by sanitary sewers leading to an adequate treatment plant at Fields Point, from which the effluent discharges into Narragansett Bay. At present there are no other sizeable sewered areas in the watershed, so that no large volume of domestic waste reaches any watercourse through a small number of outfalls. As along other New England streams, there are numerous small private drains from either individual houses or factories on the river bank. Most of such outlets are inconspicuously located. Certain of the larger mills have installed sewerage systems equipped to carry the sanitary sewage from both their factory buildings and the adjacent mill homes through septic tanks and slow sand filters, thence to the river. Paragraphs 15 a and b of this Appendix describe the sewerage systems and sewage treatment plants being constructed in West Warwick and Cranston.

Nearly all of the numerous villages in the Pawtuxet Watershed depend on antiquated sanitary facilities such as outhouses, cesspools, and septic tanks. The only item in favor of these three disposal methods is the fact that in most cases the facilities are located not directly on a watercourse, so that while contributing to the local problem of groundwater pollution they do not add to the more general problem of stream pollution. Septic tanks when properly serviced and not overloaded are satisfactory. Few chemical toilets are in use in this vicinity.

7. Industrial wastes.

a. State activity. - According to reports of the Rhode Island Board of Purification of Waters, there is a commendable disposition on the part of manufacturers to aid in elimination of pollution caused by their processing wastes. Several such concerns have already installed treatment plants and others are contemplating construction of purification systems. Most private concerns, however, are in the economic position of being obliged to wait until municipal sewerage facilities are furnished to take care of their industrial wastes. The Rhode Island Board has made surveys and prepared reports on the treatment of wastes of several concerns, and the data obtained are available to sanitary advisers of the various plants. In other instances, plans prepared by manufacturers are submitted to the Board for consideration and report, to protect the interest of the public. In September 1939 the Rhode Island State Planning Board started a pollution abatement report project for the Blackstone River. Since industrial processes and wastes in the latter stream are of similar nature to those in the Pawtuxet, certain benefits in the way of improved treatment methods may be derived from the chemical research to be included in the project.

b. Type of manufacturing wastes. - The Pawtuxet River, being highly developed industrially, must accommodate large volumes of plant wastes, chiefly textile. Discharge from textile mills is generally alkaline, dilute, and containing much spent dye coloration. Turbidity is generally heavy and persists not far below its origin. Most textile processing is done in batches and not in continuous operation, so that conditions below any one plant are variable from time to time with respect to volume, concentration, color, turbidity, and odor. Odors present are generally not as objectionable as in sanitary sewage but are often strongly ammoniacal. Most dye rinses are exceedingly dilute and carry very light coloration. The economics of textile processing prohibits the dumping of strong batches of unused dye solutions. A mitigating factor in the disposal of dye wastes in streams is their germicidal action. The latter is often true in the case of textile bleaches which contain nascent chlorine or oxygen as do many water purifiers such as chloride of lime. Very dilute acid solutions are used for "stripping", the removal of color from fabrics. The dyes used in modern textile plants are principally synthetic organic derivatives of aniline. These compounds are highly complex, stable, and not readily affected by other reagents present. During the field inspection, fish were found swimming in the immediate vicinity of some of the textile finishing plants which were at the time discharging wastes into the stream. Unlike other southern New England river valleys, there are few metal industries, and therefore acid wastes are not present to any marked degree. No important sources of pickling acids or electroplating wastes could be found in the Pawtuxet Basin. Small patches of oil were found on the streams near several of the industrial plants, but in no case was the pollution from this source considered of major importance. Suspended solids, objectionable in appearance and of industrial origin, were noted at only one plant. Here the wastes were so bulky that they floated on the surface in large masses, but did not move with the current, and the river was clear a few hundred feet downstream.

8. <u>Water analysis.</u> - The State of Rhode Island in 1924 collected and analyzed river samples from seven points along the Pawtuxet River and its branches. The monthly results were averaged to give the summary in Table I.

TABLE I

WATER ANALYSIS - PAWTUXET RIVER - 1924

Figures given are averages of monthly values

Station	Chemical Components in Parts per Million							
	Albuminoid Ammonia	Free Ammonia	Nitrates	Total Solids	Loss on Ignition	Hardness	Alkalinity	Chlorides
North Branch at Hope	.120	.027	.14	37.	13.	1.05	0.65	2.8
North Branch at Clyde	.155	.023	.17	39.	13.	0.96	0.73	3.2
Southwest Branch at Washington	.148	.048	.18	42.	16.	0.78	1.10	3.6
Southwest Branch at Riverpoint	.170	.080	.20	49.	17.	0.92	1.11	4.7
Pawtuxet River at Natick	.155	.052	.22	51.	20.	1.13	1.20	4.7
Pawtuxet River at Pettaconsett	.162	.057	.20	51.	17.	1.38	1.08	4.8
Pawtuxet River at Warwick Avenue	.200	.077	.21	64.	21.	1.63	1.75	6.3

The analytical results show a similar trend with regard to most of the constituents determined. The North Branch is less polluted than the Southwest. However, waters of the latter have a lesser degree of hardness. The Pawtuxet, because of population distribution, receives its greatest degree of wastes in the lower reaches. Here again the situation will be ameliorated by projects under construction. Differences in the two branches may be attributed to the character of the watershed and the storage ponds thereon. Some sanitary benefit results from the large amounts of oxygen made available through the vegetal growths present in the stream along most of its length. Numerous swamps act as settling basins, and in some cases are of sufficient density to serve as natural filters.

9. Periodic trend. - Prior to the utilization of the upper reaches of the North Branch for its water supply in 1926, the City of Providence maintained at Pettaconsett on the lower Pawtuxet River a station which pumped and filtered river water for municipal use. From 1900 to 1925, periodic sampling of the intake water was undertaken by the State Board of Health. Results of the analyses furnish an index of the quality of the water with respect to time, as corrections were applied to account for the varying flow depending on rainfall. Variations in business and industrial conditions have a marked effect on the amounts of industrial pollution discharged into the river. In general, a comparison of the results of analyses from 1900 to 1924 indicates a gradual increase of pollution, as judged from the free and albuminoid ammonia and nitrates, but the total solids and loss on ignition indicate the contrary.

10. Seasonal variations. - Results of dissolved-oxygen determinations indicated that the river upstream of Pettaconsett is nearly always above the safe minimum for oxygen content. From Hope to Clyde and between Washington and Riverpoint, there is only a slight decrease in oxygen content. Below these points to Natick there is a 5 to 15 percent decrease during the summer and fall season. During the summer, the oxygen content is lower at Pettaconsett than at Natick, due to manufacturing wastes entering this reach. At Clyde, the large textile plant will discharge its wastes into the new West Warwick sewer system. Seasonal variations in dissolved-oxygen content were investigated by the State Board of Health and found to be slight, with the worst conditions prevail-

ing generally in July and August. The Pocasset River at Pontiac Avenue in Cranston shows at times an almost complete depletion of dissolved oxygen, creating objectionable odors along its lower course. Completion of the new Cranston sewer will entirely remedy this situation.

11. Refuse and garbage. - Several small dumping grounds are located along the stream banks below high-water levels. While not important sources of stream pollution, any general waterway improvement program should consider these. No garbage dumps or piggeries were found to be located near the Pawtuxet River or its tributaries.

12. Sanitary conditions along streams of the Pawtuxet River Watershed. - The following findings are based largely on the field inspection of September 7, 1939, and are described in downstream sequence by rivers and towns.

13. North Branch. - The larger portion of this watershed, serving as the source of the municipal water supply for Providence, is of an excellent standard of sanitation. Regular water supply company restrictions prevail to prevent contamination. Above Kent Dam there are no known sources of stream pollution. The Providence Department of Public Works, in its operation of Scituate Reservoir, is governed by several minimum flow requirements. Table II, following, lists these limitations:

TABLE II

Requirement No. 1

MINIMUM FLOW IN MILLION GALLONS

	Scituate	Arkwright Dam	Clyde
Weekdays	0.5	6.0	-
Sunday	0.5	-	-
Weekly	-	-	72.0

Note: If the above minimum discharges were considered to be maintained uniformly over the entire period, the flow computed in c.f.s. would be:

0.5 m.g.d. = 0.77 c.f.s.
6.0 m.g.d. = 9.28 c.f.s.
72.0 m.g./wk. = 15.9 c.f.s.

However, no specification is included as to instantaneous minimum flow.

Requirement No. 2

70 m.g.d. minus Daily Consumption (27 m.g.d. in 1935)

MUST BE DISCHARGED, EXCEPT IF RESERVOIR IS NOT FULL ON JUNE 1st, and until filled - - -

65 m.g.d. minus Daily Consumption MUST BE DISCHARGED.

From Table II it may be computed that the mean daily minimum flow, based on the 1935 water consumption, is $\frac{70,000,000 - 27,000,000}{7.48 \times 86,400} = 66.5$ c.f.s. Since estimated population increases have not taken place in the Providence area in the past decade, it is safe to assume that water consumption will increase only slightly as other outlying communities are tied in to the water supply system. Therefore, based on present population trends, suitable minimum flow is assured. The construction of treatment plants in the meantime will more than offset any possible flow reduction. Description of the stream by communities follows:

Hope. - River clear. Little flow (3 ± c.f.s.) below dam. About 90 c.f.s. in mill canal. Small outfall at textile plant. Outhouses and cesspools at mill houses.

Jackson. - River clear. One laundry discharging clear water into stream through tailrace.

Fiskeville. - River clear and clean in appearance at gaging station. Flow at time of inspection was 98 c.f.s., or slightly less than 1 c.f.s./sq.mi. of the 101.6 square miles gaged.

Arkwright. - River and banks clean below textile finishing plant; fish in river. In canal below plant about 8 c.f.s. of flow, odorless, turbid, and slightly red in color, probably from a Turkey Red dye. Canal reaches river about 300 feet downstream after passing through a dirty swamp. Discharge from the marsh was turbid and contained floating oil and scum in small quantities.

Harris. - Gray, turbid discharge from dyehouse on right bank. No objectionable effluent visible from large textile plant on opposite bank. Good flow and some rapids in river below mills. No odor.

Phenix. - River very turbid at headwater of dam below Phenix Center. Numerous small outfalls present. Some chemical odor. Water probably neutral as evidenced by presence of polliwogs.

Clyde. - Large textile mill not operating at time of inspection. Water clear, but stream-bed rust-colored. Evidence that industrial wastes are discharged normally. Below Clyde, river has good flow, slight degree of turbidity, some odor.

Riverpoint. - Gray turbidity in stream below textile mill. Some suspended solids present. Little flow at tailrace.

14. Southwest Branch. - Below Flat River Reservoir dam, about 90 percent of the fall is developed in a series of small mill dams. Sanitary conditions on the stream are improved by the large amount of regulation afforded by storage provided by numerous ponds and reservoirs in series with Flat River Reservoir. The flow is regulated entirely for the benefit of downstream plant owners belonging to the Quidnick Reservoir Company, which operates the storage reservoirs on the Southwest Branch. Unlike the Scituate development, there are no public guarantees regarding low-water flow. With the exception of a small dyeing establishment far upstream at Coventry, there are no possible pollution sources above the community of Washington. Descriptions of stream conditions in downstream order follow:

Washington. - River clear at dam except for slight amber coloration, probably of algal origin. Discharge approximately 100 c.f.s. at time of inspection. One small-sized outfall seen.

Anthony. - River in same condition as at Washington. Rapids below dam provide beneficial aeration.

Quidnick. - Water above dam clear. Natural pool in river at New York, New Haven, and Hartford Railroad bridge used for swimming. Dyeworks not discharging wastes. Cesspools used at mill houses.

NOTE: All mills and communities farther downstream on the Southwest Branch are included in the area served by the West Warwick project now under construction.

Crompton. - The textile mill and mill houses here are served by a treatment plant consisting of a large septic tank and sand filters, the effluent discharging into the river. On the left bank opposite the textile plant is located a small chemical factory, to which no discharge was traceable. In the tailwater of the textile mill, conditions were probably more offensive than at any other point in the entire watershed, except possibly Crawford Brook and Pocasset River, seq. The water contained concentrated purple or indigo dye coloration, and had no perceptible flow. Sanitary sewage, oil blotches, and a heavy, viscous, tan and gray-colored foam about 1/2 inch thick were floating. At the highway bridge on the main river a short distance below, only the purple dye was evident. The river was more offensive to the sight than to the smell. It was not apparent why this material was by-passing the treatment plant, which appeared to be in working order.

Crawford Brook. - Entering the Southwest Branch a few miles below Crompton is the highly-polluted, slow-flowing Crawford Brook. Its surface was covered with a heavy scum and much vegetation of a mossy variety. The chief difficulty seems to center around the stagnant character of the stream, which in some places resembles an open sewer and in others a marshy settling basin. Most of the sewage originates in Centerville, which will be included in the West Warwick sewer.

Arctic. - At the dyeworks a few miles upstream of Arctic, the river is very turbid, pink or brown in color, with a flow of about 100 c.f.s. Some suspended solids were evident. Vegetation in the stream, consisting chiefly of weeds, was coated with slime. Some oil film was present both on the forebay and on the tailwater of the dam.

Riverpoint. - (Upstream from confluence with North Branch.) No pollution was noticeable at the soap factory. Above this plant the stream was turbid and had an ammoniacal odor. Two textile mills were discharging industrial wastes into the river, which is 75 feet wide at this point. One 6-inch pipe, flowing 1/10 full, was imparting color to the entire stream. A thin oil film extended from the left bank to mid-river. There were several 6-inch drains and one 3-foot-square outfall. Mill homes upstream had outhouses.

15. Pawtuxet River. - Since the two sewage treatment plants now being built will largely eradicate existing sanitation problems on the Pawtuxet, their descriptions are given here.

a. West Warwick project. - At present there is no sewerage system in the town, which has a population of about 18,000. The Southwest Branch enters the southwestern part of the town, whence it flows in a northerly direction to its confluence with the North Branch at mile 10.6, from which point the river flows easterly forming the West Warwick-Warwick Town line. There is a large volume of industrial waste, especially from the textile plant at Clyde, which uses more water than the remainder of the town. In these wastes are some objectionable chemical substances which it may be found necessary to treat because of their concentration, before entrance into the sewers. In most cases the industrial plant effluents are not judged to be particularly high in chemical content. No difficulties are anticipated from laundry wastes, which are negligible when compared to the vast quantities of dilute wash water discharged from the textile plants. The engineers in charge of the construction, having also handled most of the water supply problems for the town, are well acquainted with the quantities of industrial wastes from the water usage figures.

(1) The sewer main will pursue the following course: starting in the southwestern corner of the town along a brook, it will parallel this stream to the Southwest Branch of the Pawtuxet near Crompton, cross the river, extend northerly paralleling the stream to Riverpoint, where it will again cross the river paralleling the Pawtuxet River to a point westerly of Natick, where another crossing will be made to the site of the treatment plant, which will be at the extreme northeasterly corner of the town, to the west of the railroad and just north of the Pawtuxet River. The site is in lowlands which were inundated to a depth of 5 or 6 feet in the flood of July 1938. However, the structures as designed will be waterproof, sufficiently heavy to resist floating, and above any recorded high-water elevations. They will be able to function properly during a flood similar to that of July 1938. The plant, which is to be of the "activated sludge" type, is to comprise the following steps: (1) preliminary sedimentation; (2) aeration; (3) final sedimentation; (4) heated sludge digestion; and (5) chlorination of effluent. It is planned to use the sludge for fill in the low-lying area adjacent to the plant.

(2) The estimated quantity of waste to be treated is 1,500,000 gallons per day, although the design capacity is about 3,000,000 gallons per day. The area to be sewered includes almost 100 percent of the town of West Warwick, omitting only very small areas where sewers are not economically justified. Provisions are also to be made for possible expansion by including wastes from areas farther upstream along the Southwest and North Branches of the Pawtuxet River in the vicinities of Quidnick, Anthony, Harris, Fiskeville, and Arkwright. Also it is hoped to be able to accommodate the badly polluted water of Crawford Brook which, originating in Coventry township, enters the Southwest Branch of the Pawtuxet a few miles upstream of Arctic. The sewerage system will not be used until the treatment plant is in complete readiness to accommodate the wastes therefrom.

b. Cranston project. - The plant, construction of which was begun in June 1939, was scheduled to be completed by the Work Projects Administration in four years, but working schedules have been increased recently to a point indicating completion during the summer or fall of 1942. The system will consist of a sanitary sewer with an "activated sludge" type treatment plant with a capacity of 8 to 9 million gallons per day. A plant of this size will care for 50 percent of the city's area and 85 percent of the population, which was 44,500 in 1930. Only the outlying rural sections will not be taken care of by the system. If desired, the capacity may later be increased to include the village of Thornton. The sewerage system will contain 87 miles of mains, 3-1/2 miles of force mains, and 9 pumping stations. The treatment process will involve sedimentation, oxidization by aeration, sludge digestion, sludge drying and burning.

(1) The approximate traverse of the sewer has been traced on a map and is generally as follows: paralleling the Providence-Cranston

City line, following in a counter-clockwise direction to the Johnston-Cranston Town line through Thornton, westerly to Meshanticut Brook, crossing the New York, New Haven, and Hartford Railroad, flowing easterly around Sockanosset Reservoir, whence it flows southeasterly to the treatment plant (exact location not yet determined) near the Old Pettaconsett pumping station on the Pawtuxet River. Among the communities included in this area are those of Cranston, Knightsville, Wayland, Auburn, and Edgewood. The sewerage system will be most complete in the populated zone adjoining Providence and will eliminate all direct outfalls on Narragansett Bay. It may later be found justifiable to include in the sewered area communities in Johnston, such as Simmonsville, Hughesdale, and Morgan Mills.

c. Following is a description of stream conditions along the Pawtuxet as revealed in field inspection of September 7, 1939:

Twin Bridges. - Stream bottom visible to two-foot depths. No odor. No outfalls found.

Natick. - At the bridge above Natick, the river was slightly turbid, odorless, and had sufficient flow. A rubbish dump was found on the right bank upstream. At Natick, the large mill is now idle and being liquidated. The stream is clear and contains much vegetal growth. Some storm sewers, a small metal dump, and many outhouses were found on the river bank.

Meshanticut Brook. - Water at mouth clear with little flow.

Pontiac.-- At dam above textile finishing plant, river was slightly turbid with small oil patches present. The mill pond had heavy plant growth, including pond lilies. About twenty outfalls, varying from 3 to 18 inches in diameter, were found. One 18-inch iron pipe, flowing about one-fourth full, was discharging reddish dye water. A 1-inch pipe was emitting what appeared to be a dichromate solution. Waste from the plant, which at present employs about 300 hands, discharges into the river, which was turbid downstream.

Old Pettaconsett pumping station. - The abandoned bridge here constitutes a stream obstruction with some damming action caused by lumber and fallen trees. An oil film extends across the stream. Below the bridge the stream is clear with the bottom visible.

Pocasset River. - This tributary, 10.4 miles in length, rises in the town of Johnston, flows southeasterly through Hughesdale, Thornton, and Cranston, flowing into the Pawtuxet below Pettaconsett. Summer flow is usually about 20 c.f.s. Velocities are generally low although there are occasional reaches of swift water. Above Hughesdale the area is largely rural with no direct pollution. At Morgan Mills some pollution enters in the form of overflow from septic tanks. At Thornton, the stream was clear at the Plainfield Street bridge. Deposition of rubbish on stream banks was evident. From this point the river flows through open country to Print Works Pond, after receiving outflow from two controlled storage ponds (Randalls and Dyers Ponds). The only major source of pollution is the print works. Here the stream was gray in color, very turbid, and possessing the odor of strong alkaline soaps. A four-foot masonry outfall was discharging a small volume of brown-colored waste, and some oil was present. The discoloration from the print works was evident for the entire distance to the river mouth. Odor becomes gradually less below Cranston center. At Reservoir Avenue the stream is very dirty and heavy with gray suspended matter, some of which is deposited on the banks. About 2000 feet above the mouth the flow was about 25 c.f.s., no odor was apparent, and no deposition was taking place.

Cranston. - The lower reaches of the main river are heavily populated and industrialized. No large sources of industrial pollution were found, although some small outfalls were in use. Several of the streets in this vicinity have storm-water drains leading to the nearest watercourse. In the vicinity of Broad Street many private sewer drains now lead directly to Pawtuxet Cove.

16. Summary.

a. The pollution problem in the headwaters of the Pawtuxet River Watershed is minor because of the following conditions:

(1) Scarcity of population and lack of industries.

(2) Use of North Branch for municipal water supply.

(3) Use of Southwest Branch for conservation.

b. The two greatest sources of pollution exist in Cranston and West Warwick. These will be entirely abated by 1942 by construction now in progress.

c. A suitable minimum flow is being maintained in both branches.

d. Certain industrial plants are at present causing stream pollution. Where these concerns will not be served by municipal projects now under construction, remedial measures must be undertaken at the plants. The Rhode Island Board of Purification of Waters cooperates with manufacturers by providing advisory service to help solve pollution problems affecting public interests. No rigid rules for eliminating or reducing the contamination of waterways by industry can be formulated when it is realized that much depends on the economic resources of each manufacturing establishment.

17. Recommendations.

a. Pollution abatement in the Pawtuxet River Watershed cannot be economically extended by use of dilution methods. Reduction in hardness by dilution is not justified, since the water is now sufficiently soft. No additional storage to increase low-water flow is recommended.

b. At the State Institutions at Sockanosset, where construction of a sewage treatment plant has been initiated but not completed due to insufficient funds, it is recommended that plans be amended so that sewage may enter the Cranston sewer.

c. It is recommended that, as economic conditions permit, the sewers now under construction be extended to include Thornton in the town of Johnston, areas along Crawford Brook in the township of Coventry, and villages upstream along the North and Southwest Branches of the Pawtuxet River.

d. Conditions at Crompton should be improved so that a greater portion of the objectionable sanitary and industrial wastes will go through the existing treatment plant.

e. As new research developments progress and economically sound methods are found for treating industrial wastes, measures should be taken to encourage their use, particularly at plants so isolated as not to be included in sewered zones. In some instances the development of valuable by-products may follow.

f. The practice of locating refuse dumps on stream banks, below high-water level, should be discontinued.

SECTION II - DETAILED ESTIMATES AND COSTS

GENERAL

1. Scope. - Several methods of flood control for the Pawtuxet River have been considered in the main body of this report. Those considered worthy of further study have been grouped into four schemes and the costs and benefits of each plan comprising these schemes have been studied in detail. Section II of the Appendix explains the design and cost estimates of each plan included in the four schemes, namely, Clyde Levee, Warwick Levee, Cranston Levee, Broad Street Improvement, Cranston Cut-off, and Pontiac Diversion, and one plan not included in the four schemes, namely, Washington Reservoir. The locations of the above plans are shown on Plate 1 of the Appendix.

2. Data available for survey. - Topographical features have been mapped by the plane-table method at the sites of the proposed projects wherever suitable maps were not obtainable from other sources. At the Washington Dam site, the survey was limited to sections along the axis of the dam and dike, and river profiles. Subsurface conditions at the levee sites have been explored by core and auger borings. The soil samples have been analyzed in the District Soils Laboratory. At the Washington Dam site subsurface investigations were not considered necessary, as visual inspection disclosed suitable ledge for the foundation of hydraulic structures and exposed banks revealed the nature of the materials in the glacial depositions at the site. Borings and seismic determinations of the location of bed-rock have been made at the proposed site of the Pontiac Diversion. At all sites the data available have been adequate to complete a safe and economical preliminary design.

3. Basis of estimate. - The costs of the projects have been estimated upon the basis of a design which would provide the most economical and safe construction for the particular site. Estimates of quantities have been made upon the basis of the net outlines of the adopted design

and foundation requirements.

4. Unit prices. - Unit prices have been based upon construction cost for similar types of work now in progress in New England with due consideration for the method of construction, and the availability and location of materials at each site. Information on the cost of the several highway bridges proposed over the Pontiac Diversion and for the enlargement of the Broad Street Bridge has been obtained from the Highway Department of the State of Rhode Island.

5. Contingencies, engineering and overhead. - The construction costs have been increased by 20 percent to cover contingencies anticipated because of the preliminary character of the survey data, foundation explorations, and design and construction difficulties. Engineering and overhead have been estimated at 15 percent of the construction costs.

6. Rights-of-way and damages. - The estimated costs of rights-of-way and the estimated damages which would accrue by reason of acquisition of lands and construction of the projects have been based upon information secured from local officials, upon assessed values, and upon field reconnaissance. Land takings would include the sites, adjacent borrow and spoil areas necessary to execute the work, and, in the case of the Washington Reservoir, the reservoir area. The spillway of Washington Reservoir would be overtopped only by floods of rare occurrence and it has not been considered necessary to purchase land in the reservoir area above the elevation of the spillway crest. Damages include the severance of land and the demolition or cost of moving existing improvements in the affected area. A factor of 20 percent has been added for legal costs, costs of acquisition, and general expense.

7. Highway, railroad and utility relocation.- Plans for relocation of the highways and railroads involved have been based on the results of field reconnaissance and the use of existing maps and profiles.

Existing facilities have been reproduced and the existing standards of construction of the affected utilities would be maintained as far as possible. In view of the preliminary nature of the studies and the approximate data available for quantity computations, contingencies on railroad and highway relocations have been estimated at 15 percent, and engineering at 10 percent.

8. Basis of annual cost. - Federal and non-Federal annual costs have been computed at the interest and amortization rates authorized by letter from the Chief of Engineers dated August 14, 1939. The Federal interest rate is 3-1/2 percent and amortization is 3-1/2 percent, compounded annually. Interest during construction at 3 percent per annum for one-half the cost has been added to the Federal investments wherever the construction period is estimated at 2 or more years. Non-Federal rates are 4-1/2 percent for each of the above items. Federal annual costs include interest and amortization of the total Federal investment. The non-Federal annual costs include, in addition to interest and amortization of the non-Federal investment, tax loss computed at 2 percent per annum. Annual expenditures for operation and maintenance of the levee projects and the Pontiac Diversion will be borne by non-Federal interests. The distribution of Federal and non-Federal first costs, the useful life of the structures, and the maintenance and operation costs of the several projects are discussed in more detail in the following pages under the project concerned.

WASHINGTON RESERVOIR

9. General. - Washington Dam would be located on the Southwest Branch of the Pawtuxet River near Washington, R. I. The reservoir area would include all of the existing Flat River Reservoir and a large additional area in the Mishnock River Valley. It would have a drainage area of 61.9 square miles and has been designed to provide a storage

capacity equal to six inches of run-off from this area or 19,800 acre-feet. It would furnish a measure of flood protection to the Southwest Branch below the dam, and to the main stem of the Pawtuxet River to its mouth.

10. Highways. - State Highways Nos. 3 and 117 are the principally traveled arteries through the proposed reservoir area. The former is a four-lane concrete highway in the vicinity of the proposed dike the pavement changing to the dual type, i.e., a 24-foot bituminous center with a 12-foot concrete lane on each side, a short distance west of the aforementioned dike. This road is one of the principal thoroughfares between Providence, R. I., and New London, Conn. State Highway No. 117 is a two-lane bituminous surfaced road crossing the axis of the main dam in the vicinity of the Town of Washington, R. I. It is a secondary road, extending in a general easterly and westerly direction.

11. Railroad. - The single track railroad which would be affected by the proposed reservoir is a branch line of the New York, New Haven, and Hartford Railroad. At the present time it is used solely for freight service.

12. Other public works. - The New England Power & Light Company has a 4-wire distribution line which would cross the axis of the main dam. There is also a 22-wire telephone line of the New England Telephone & Telegraph Company in this locality. Where the proposed dike would cross Highway No. 3, there is a joint line of the two companies carrying two power wires and six telephone wires. It would be necessary to relocate approximately two miles of these pole lines.

13. Dam. - A layout of the dam and appurtenant works is shown on Plate 2 of the Appendix.

a. Geology. - Ledge rock occurs above the right abutment and along the right bank below the site. The left abutment would be formed in glacial deposits of sand and gravel.

b. Available materials. - Sand and gravel, suitable for concrete aggregates, are available in the glacial deposits near the site. Pervious materials are available within 0.5 mile, and impervious materials within 1 mile.

c. Dam and appurtenant works. - The dam, of rolled-fill earth construction with a rolled-fill earth dike, would be located across the Southwest Branch of the Pawtuxet River. The dike would close the gap at the rim of the reservoir located southeast of the dam at State Highway No. 3, 1,000 feet east of Mishnock River. A concrete gravity overflow and gate section would be located on the axis of the dam between the right abutment and the bank of the river. The total length of the dam would be 2,500 feet, 2,100 feet being earth fill with a top elevation of 267.5 feet above mean sea level, 47 feet above the stream bed. The dike would also be built to this elevation. Its length would be 1,650 feet, and the maximum height would be 23 feet. The top elevation would provide a surcharge of 10 feet, with 5 feet of freeboard.

d. Embankment. - The rolled-fill earth dam would have a top width of 20 feet. It would consist of an impervious core within a random-fill section. The impervious core would extend from top to bottom, and would be keyed into the existing ground with a cut-off section 5 feet deep along the axis of the fill. Side slopes of the core would be 3 vertical on 1 horizontal and the outside slopes of the dam would be 1 on 3. Rock would be dumped on the upstream face of the dam and in the toe drain. The right embankment would end at a concrete retaining wall at the gate section. The dike would have a crown width of 10 feet and side slopes not steeper than 1 on 2. The random section would have an impervious blanket protected against wave action by riprap.

e. Spillway. - The spillway, a solid concrete overflow section, 245 feet long, would be built on ledge rock. Its crest elevation would be 252.5 feet above mean sea level, and the discharge capacity, under a 10-foot surcharge, would be 24,000 cubic feet per second, or the equivalent of 388 cubic feet per second per square mile of drainage area. The gate section would be located at the left end of the spillway. At the right end of the spillway a short non-overflow section of concrete would connect it to the right abutment.

f. Outlet. - Four outlet conduits would be provided through the base of the gate section. Each of the conduits would be provided with a gate 3 feet by 4 feet, operated by hydraulical cylinders placed in a gallery above the gates. Above the outlet conduits, two mechanically operated Stoney gates, 9 feet wide, would ensure flood storage above elevation 243.7 feet, mean sea level.

g. Conservation storage. - Conservation storage equivalent to the existing storage in the Flat River Reservoir, which lies wholly within the reservoir of the proposed dam, would be provided. The existing storage is essential to the industrial establishments downstream for both water power and industrial uses, and the elimination of these water rights would involve large damage claims. Flood storage would be provided above elevation 243.7 feet, mean sea level.

h. Estimate of cost. - The Federal investment would include the construction cost of the dam, the cost of lands and damages, and the relocation of highways, railroad, and public utility lines. There would be no non-Federal investment. The project would be amortized in fifty years, with the exception of concrete and gate costs which would be amortized at 1 and 3 percent per annum, respectively. The annual charge of $3,500 would be made for general overhead and maintenance of the dam. Maintenance of concrete structures and gate equipment has been computed at 1 and 3 percent, respectively. Operation expenses have not been included because the present operation of the Flat River

Reservoir would be transferred to the new site. The estimated costs of the Washington Dam are given in the following table:

Cost Estimate for Washington Reservoir

Item No.	Item	Quantity	Unit cost	Amount	Total
1.	Construction cost				
	Clearing	500 acres	$ 50.00	$ 25,000	
	Stream control		L.S.	1,000	
	Stripping	12,500 c. y.	0.50	6,200	
	Excavation, common	12,700 c. y.	0.30	3,800	
	Excavation, rock	1,340 c. y.	3.00	4,000	
	Pervious borrow	138,700 c. y.	0.35	48,500	
	Impervious borrow	15,800 c. y.	0.50	7,900	
	Placing embankment	154,500 c. y.	0.10	15,400	
	Riprap, dumped	15,500 c. y.	2.00	31,000	
	Toe drain, rock	1,800 l. f.	7.60	13,700	
	Toe drain, gravel	1,650 l. f.	3.20	5,300	
	Concrete, Class A	920 c. y.	15.50	14,300	
	Concrete, Class B.	5,020 c. y.	12.00	60,200	
	Reinforcing steel	92,000 lbs.	0.05	4,600	
	Gates and machinery		L.S.	10,700	
	Gatehouse and miscellaneous		L.S.	5,000	
				256,600	
	Contingencies		20%	51,300	
				307,900	
	Engineering		15%	46,100	
	Total				$ 354,000
2.	Relocation of railroads and utilities				
	Single track railroad, branch line	2.36 mi.	L.S.	91,000	
	Telephone lines	2.0 mi.	L.S.	1,200	
				92,200	
	Contingencies		15%	13,800	
				106,000	
	Engineering and overhead		10%	11,000	
	Total				117,000
3.	Rights-of-way and land				
	Land		L.S.	107,300	
	Improvements		L.S.	142,700	
	Cemetery relocation		L.S.	86,000	
				336,000.	
	Legal, overhead, and general expense		20%	67,000.	
	Total				403,000.

4. Highway relocation

48 ft. Dual-type State highway	0.63 mi.	L.S.	$ 80,400
18 ft. Bit.-mac. State highway	1.1 mi.	L.S.	126,500
			206,900
Contingencies		15%	31,100
			238,000
Engineering and overhead		10%	24,000
Total			$ 262,000

5. Grand total capital cost 1,136,000

6. Total annual cost

	COST	TOTAL
(a) Federal investment		
Construction cost $256,600 by 1.38	$354,000	
Railroad & utilities relocation $92,200 by 1.27	117,000	
Highway relocation $206,900 by 1.27	262,000	
Rights-of-way and damage $336,000 by 1.20	403,000	
Interest during construction $1,136,000 by .03 by 2 by 1/2	34,000	
Total Federal investment	1,170,000	
(b) Federal annual carrying charge		
Interest $1,170,000 by .035	40,950	
Amortization of obsolescence and depreciation:		
Earth embankment $161,800 by 1.38 by 1.03 by .0076	1,750	
Concrete $79,100 by 1.38 by 1.03 by .01	1,130	
Gates and machinery $15,700 by 1.38 by 1.03 by .03	670	
Railroad, utility, and highway relocation $299,100 by 1.27 by 1.03 by .0076	2,970	
Rights-of-way and damage at $336,000 by 1.20 by 1.03 by .0076	3,160	
Maintenance and operation		
Dam L.S.	3,500	
Concrete $79,100 by 1.38 by .01	1,000	
Gates and machinery $15,700 by 1.38 by .03	650	
Total Federal annual carrying charge		55,870
(c) Non-Federal investment (None)	0	
(d) Non-Federal annual carrying charge		
Loss of tax $250,000 by .02	5,000	
Total non-Federal annual carrying charge		5,000
Total annual cost		60,870

CLYDE LEVEE

14. General. - Most of the flood loss on the North Branch has been concentrated in a small area on the left bank at Clyde, one-half mile above the mouth. The Clyde Levee has been designed to provide flood protection for this area.

15. Description of flooded area. - The area liable to inundation by flood waters includes a large modern print and dye works, a lumber yard, several blocks of stores and houses, and a gasoline station.

16. Flood losses. - The direct losses within the protected area amounted to $38,500 in the March 1936 flood and $37,500 in the July 1938 flood. The maximum flood of record occurred in February 1886 with a peak stage 8 feet higher than in 1936 and 1938. Contemporary newspapers report damage of $18,000, but with the present development of the area far greater losses would have been sustained, estimated at $400,000. The average annual direct losses have been computed as described in paragraph 39 to be $22,320. The total average annual loss is summarized in the following tabulation. Indirect losses have been estimated as slightly greater than the direct losses. The average annual depreciation losses have been empirically computed as $260, or 0.1 percent of the value of the property. More important depreciation losses would result were a really great flood to occur. With a levee built to maximum predicted flood grade, the average annual benefits would be equal to the annual losses, as follows:

Annual direct losses	$22,320
Annual indirect losses	26,780
Annual depreciation	260
Total average annual losses. . . .	49,360

17. Levee design flood. - The levee has been designed to pass a flood equal to the maximum predicted flood (See paragraph 30 of the

report), with a freeboard of 3 feet for the earth levee, and 1 foot for the concrete wall section.

18. Alignment. - The levee protection proposed at Clyde is shown on Plates 3 and 4 of the Appendix. The levee would protect 20 acres of lowland located south of the Pawtuxet Valley branch line of the New York, New Haven and Hartford Railroad. The alignment would begin at the railroad, would follow the tailrace of the Lippitt Mill, and thence would follow the river. At a point 700 feet downstream from Main Street it would diverge from the river to pass around the buildings of the Allied Textile Printers Mill and terminate in the vicinity of Clyde Street at the railroad. The over-all length of the levee would be 3,100 feet. Channel improvements are proposed to rectify restrictions of the channel caused by the levee. The improvement would include the widening of the channel below Main Street Bridge.

19. Geology. - The most prominently developed stratum in the foundation is made up of pervious sand and gravel, averaging about 12 feet in thickness. Throughout about half the length of the proposed levee, the upper portion of the foundation comprises fill materials of cinders, sand, and gravel. Quartzitic rock, which occurs at a depth of from 15 feet to about 25 feet, is directly overlain in places by moderately pervious beds of mixed sand, silt, and gravel.

20. Embankment. - The maximum hydrostatic head to which the earth embankment would be subjected is 15 feet. The section would have a crown width of 10 feet, a riverside slope of 1 vertical on 2-1/2 horizontal and a landside slope of 1 on 2. The embankment would consist of a random section and an impervious blanket on the riverside slope. The random material would be a mixture of gravel, sand, and silt obtained from the foreshore at the lower end of the levee and the blanket material of fine sand and silt obtained within a distance not exceeding one

mile from the site. Underground seepage would be controlled by a horizontal pervious filter and toe drain. The section of railroad embankment west of Main Street would be treated with an impervious blanket to prevent excessive seepage through it.

21. Concrete walls and structures. - Concrete walls are proposed where space would not permit the use of an earth section. The walls would be of the cantilever type and would vary in height from 6 to 13 feet. A steel sheet-piling cut-off and toe drains would be provided. The existing canal intake would be replaced with a gate-controlled conduit and headwalls through the earth embankment. Abutments would be provided at Main Street to facilitate a sand-bag closure in time of floods.

22. Riprap protection. - It is proposed to protect the earth embankment with hand-placed riprap where scour is anticipated. The remaining surfaces of the levee would be sodded.

23. Drainage and pumping facilities. - No changes or extensions to the existing drainage system which discharges into the canal would be necessary. A pumping plant having a capacity of 105 cubic feet per second at a 15-foot head would be located at the lower end of this canal to maintain the normal water level during freshets. Levee seepage would be discharged through short laterals into the canal.

24. Estimate of cost. - The total Federal investment for the Clyde Levee would include the cost of construction of the levee and pumping plant. The acquisition of lands for rights-of-way and the settlement of damage claims would be non-Federal obligations. All costs would be amortized over a period of 50 years except for the pumping plant and equipment, which would be written off in 20 years. Maintenance and operations have been computed at 2 percent of the total cost of the pumping plant and 1/2 of 1 percent of the total cost of the construction of the levee. The following table gives the estimated cost of the Clyde Levee:

Cost Estimate for Clyde Levee

Item No.	Item	Quantity	Unit cost	Amount	Total
1.	Levee construction				
	Clearing	9 acres	$150.00	$ 1,400	
	Stripping	6,500 c. y.	0.50	3,300	
	Excavation (cut-off trench)	5,600 c. y.	0.25	1,400	
	Embankment, earth	56,700 c. y.	0.65	36,900	
	Riprap	2,350 c. y.	6.00	14,100	
	Concrete, Class A	1,860 c. y.	15.50	28,800	
	Concrete, Class B	290 c. y.	12.00	3,500	
	Reinforcing steel	186,000 lbs.	0.05	9,300	
	Excavation	3,600 c. y.	0.40	1,400	
	Backfill	2,900 c. y.	0.25	700	
	Drains, concrete walls	830 l. f.	1.50	1,200	
	Drains, earth dikes	2,200 l. f.	3.50	7,700	
	Steel sheet-piling	16,000 s. f.	1.25	20,000	
	Conduit and gate at canal		L.S.	400	
	Channel excavation	20,800 c. y.	0.50	10,400	
				140,500	
	Contingencies		20%	28,100	
				168,600	
	Engineering and overhead		15%	25,400	
	Total				$194,000
2.	Drainage and pumping facilities				
	Pumping plant	1-105 c.f.s.	L.S.	60,000	
	Contingencies		20%	12,000	
				72,000	
	Engineering and overhead		15%	11,000	
	Total				83,000
3.	Rights-of-way and damages				
	Land		L.S.	13,300	
	Damages		L.S.	5,400	
				18,700	
	Legal, overhead, and general expenses		20%	3,300	
	Total				22,000
4.	Grand total capital cost				299,000
5.	Total annual cost			Cost	Total
	(a) Federal investment:				
	Levee construction $140,500 by 1.38			$194,000	
	Pumping station 60,000 by 1.38			83,000	
	Total Federal investment			277,000	
	(b) Federal annual charge:				
	Interest $277,000 by .035			9,700	
	Amortization of obsolescence and depreciation:				
	Fixed parts $140,500 by 1.38 by .0076			1,470	
	Movable parts 60,000 by 1.38 by .0354			2,930	
	Total Federal annual charge				$14,100

(c) Non-Federal investment:

Land and damages $18,700 by 1.20	$ 22,000	
Total non-Federal investment	22,000	

(d) Non-Federal annual carrying charge:

Interest $22,400 by .045	1,010	
Amortization of obsolescence and depreciation $22,400 by .0056	120	
Tax loss on land $22,400 by .02	450	
Maintenance and operation:		
Levees $140,500 by 1.38 by .005 ...	970	
Pumping station 60,000 by 1.38 by .02	1,660	
Total non-Federal carrying charge		$4,210
Total annual cost		18,310

25. Plan of construction. - The project would be completed in one construction season. The concrete walls and structures would be built before the earth embankment. Channel improvements would be carried on concurrently with the placing of the levee embankment. The remainder of the work would follow in its logical sequence.

WARWICK LEVEE

26. General. - The Warwick Levee would be located on the right bank of the Pawtuxet River, and would inclose an area extending for 1/4 of a mile on each side of Elmwood Avenue in Warwick.

27. Description of flooded area. - The area subject to flooding includes several business blocks and homes. The low-lying residential area downstream from Elmwood Avenue, known as Belmont Park, suffers frequently from high water. It contains about thirty homes of moderate value.

28. Flood losses. - Damage to dwellings and garden plots within the protected area has been estimated at $3,300 for the July 1938 flood

and approximately the same for the March 1936 flood. The flood stage reached nearly to the first floors and forced twenty-five families in the area to evacuate their homes. The section which would be inclosed by the levee is a comparatively new development so that no losses have been recorded for earlier floods, including the February 1886 flood, which exceeded the recent floods of 1936 and 1938 by approximately 6 feet. Under existing conditions such a flood would cause direct losses of approximately $37,500. From the damage-frequency relationship, the average annual direct losses have been computed at $1,980. The following table summarizes the average annual direct losses for the protected area. Indirect losses have been computed as 50 percent of the direct losses, and depreciation losses have been empirically figured at 0.1 percent annually of the value of the property.

Annual direct losses	$ 1,980
Annual indirect losses	990
Annual depreciation	190
Total average annual losses . . .	3,160

29. Levee design flood. - The levee has been designed to pass a flood equal to the maximum predicted flood (see paragraph 30 of the report), with a freeboard of 3 feet for the earth levee, and 1 foot for the concrete wall section.

30. Alignment. - The levee plan proposed for the City of Warwick would provide protection to a section known as Belmont Park, located across the Pawtuxet River from the area which would be protected by the Cranston Levee. The alignment would start at high ground west of Elmwood Avenue and would extend to the bridge at Elmwood Avenue, thence following the bend in the river to high ground at Regnier Pond. The total length of levee would be 4,200 feet. The alignment is shown on

Plate 5 of the Appendix. The levee would protect an area of 40 acres.

31. Geology. - Impervious silt strata about 25 feet thick occur throughout the foundations at a depth of about 12 feet. Overlying these sediments are numerous stratifications of coarser material, ranging from moderately fine sand to pervious sand and gravel. The upper portions of this overburden are largely fine to coarse sand, together with minor amounts of organic and vegetable material. Rock is deeply buried, occurring at a depth of at least 50 feet.

32. Embankment. - The design provides for earth levees except in restricted areas at Elmwood Avenue and at Regnier Pond. The earth embankment would be subjected to a maximum hydrostatic head of 17 feet. The embankment section, shown on Plate 6 of the Appendix, would have a crown width of 10 feet, a river-side slope of 1 vertical on 2-1/2 horizontal and a land-side slope of 1 on 2. The embankment would consist of a random section and an impervious blanket on the river-side slope. The random material would be a mixture of gravel, sand, and silt obtained from the foreshore at the bend of the river and adjacent to Regnier Pond. Above Elmwood Avenue, there is random material available adjacent to the proposed alignment. Fine sand and silt for the blanket material would be obtained within one mile of the site. Some seepage would be expected through the foundations but would be controlled by a pervious filter blanket and toe drain.

33. Concrete walls and stop-log structure. - Concrete walls would be used in the restricted areas at Elmwood Avenue and at Regnier Pond. The walls would be of the cantilever type and would not exceed a height of 18 feet above the ground. Underground seepage would be controlled by extending the shear key into a relatively impervious material and providing toe drains. A concrete stop-log structure with a removable center support would be provided at Elmwood Avenue.

34. Riprap protection. - The levee adjacent to the river from Elmwood Avenue to a point 1,000 feet downstream would be protected against scour with riprap placed on the riverside slope to within 2 feet of the top of the levee.

35. Drainage and pumping facilities. - A pumping plant of 25 cubic feet per second capacity would be provided to handle the storm run-off and levee seepage which would be carried to the plant through an intercepting sewer along First Avenue. The plant would be located at the end of the concrete wall near the outlet of Regnier Pond.

36. Estimate of cost. - The total Federal investment for the Warwick Levee would include the cost of construction of the levee and the pumping plant. The acquisition of lands for rights-of-way, the settlement of damage claims, and the construction of intercepting sewers are non-Federal obligations. All costs would be amortized over a period of 50 years, except the pumping plant and equipment, which would be written off in 20 years. Maintenance and operation costs have been computed at 2 percent of the total cost of the pumping plant, and 1/2 of 1 percent of the total cost of construction of the levee. The estimated costs of the Warwick Levee are given in the following table:

Cost Estimate for Warwick Levee

Item No.	Item	Quantity	Unit cost	Amount	Total
1.	Levee construction				
	Clearing	11 acres	$150.00	$ 1,700	
	Stripping	11,800 c. y.	0.50	5,900	
	Excavation (cut-off trench)	10,300 c. y.	0.25	2,600	
	Embankment, earth	141,900 c. y.	0.55	78,000	
	Riprap	2,440 c. y.	6.00	14,600	
	Concrete, Class A	2,340 c. y.	15.50	36,300	
	Reinforcing steel	234,000 lbs.	0.05	11,700	
	Excavation and backfill	4,200 c. y.	0.40	1,700	

(continued)

Item No.	Item	Quantity	Unit cost	Amount	Total
	Drains, concrete walls	850 l. f.	$1.90	$ 1,600	
	Drains, earth levees	3,380 l. f.	3.25	11,000	
	Steel sheet-piling	4,250 s. f.	1.25	5,300	
				170,400	
	Contingencies		20%	34,100	
				204,500	
	Engineering and overhead		15%	30,500	
	Total				$235,000
2.	Drainage and pumping facilities				
	Pumping plant	1-25 c.f.s.	L.S.	25,000	
	Intercepting sewer (30")	1,150 l. f.	6.85	7,900	
				32,900	
	Contingencies		20%	6,500	
				39,400	
	Engineering and overhead		15%	5,600	
	Total				45,000
3.	Rights-of-way and damages				
	Land		L.S.	20,500	
	Damages		L.S.	7,900	
				28,400	
	Legal, overhead, and general expense		20%	5,600	
	Total				34,000
4.	Grand total capital cost				314,000

		Cost	Total
5.	Total annual cost		
	(a) Federal investment:		
	Levee construction $170,400 by 1.38	$235,000	
	Pumping station 25,000 by 1.38	34,000	
	Total Federal investment	269,000	
	(b) Federal annual charges:		
	Interest $269,000 by .035	9,410	
	Amortization of obsolescence and depreciation:		
	Fixed parts $170,400 by 1.38 by .0076	1,790	
	Movable parts 25,000 by 1.38 by .0354	1,220	
	Total Federal annual charges		$12,420
	(c) Non-Federal investment:		
	Land and damages $28,400 by 1.20	34,000	
	Drainage 7,900 by 1.38	11,000	
	Total non-Federal investment	45,000	

(d) Non-Federal annual carrying charge:

Interest \$45,000 by .045	\$2,020	
Amortization of obsolescence and depreciation \$45,000 by .0056	250	
Tax loss on land \$20,500 by 1.20 by .02	490	
Maintenance and operation:		
Levees and drainage \$178,300 by 1.38 by .005	1,230	
Pumping station \$25,000 by 1.38 by .02 ...	690	
Total non-Federal annual carrying charge		\$ 4,680
Total annual cost		17,100

CRANSTON LEVEE

37. General. - The Cranston Levee would be located on the left bank of the Pawtuxet River extending for 1/4 mile on each side of Elmwood Avenue in Cranston. It would provide protection to that part of Cranston bordering on the Pawtuxet River which has suffered large losses in past floods.

38. Description of flooded area. - The area subject to flooding includes one large modern textile machinery plant, several business blocks and homes, and a school, all located in the City of Cranston.

39. Flood losses. - The direct losses within the protected area were \$65,700 in the July 1938 flood. In the March 1936 flood, which reached approximately the same height, direct losses totaled only \$3,700, so successful was the sand-bagging of the large textile machinery plant where most of the 1938 flood loss occurred. There are no available records of damage from the great flood of February 1886 which exceeded the floods of March 1936 and July 1938 by approximately 6 feet. However, it is estimated that should such a flood reaching the same stage now occur, direct losses would total approximately \$130,000. From the damage-frequency relationship, the average annual direct losses have been computed at \$7,550. The following table summarizes annual losses within the area which would be protected:

Annual direct losses	$ 7,550
Annual indirect losses	8,710
Annual depreciation	820
Total average annual losses . . .	17,080

40. Levee design flood. - The levee has been designed to pass a flood equal to the maximum predicted flood (See paragraph 30 of the report), with a freeboard of 3 feet for the earth levee, and 1 foot for the concrete wall section.

41. Alignment. - The Cranston Levee would provide protection for 60 acres of land in the vicinity of Elmwood Avenue. The levee would begin at high ground near the foot of Thorn Avenue, and would run at right angles to the New York, New Haven, and Hartford Railroad for a distance of 550 feet, thence parallel to the Pawtuxet River to Perkins Avenue. At this point it would turn north, tying into high ground near the railroad spur track. The levee would have a total length of 5,300 feet and is shown on Plate 5 of the Appendix.

42. Geology. - Impervious silt strata about 25 feet thick occur throughout the foundations at a depth of about 12 feet. Overlying these sediments are numerous stratifications of coarser materials, ranging from moderately impervious fine sand to pervious sand and gravel. Rock is deeply buried, occurring at a depth of at least 50 feet.

43. Embankment. - The earth embankment would be subject to a hydrostatic head up to 18 feet in a great flood. The earth section shown on Plate 7 of the Appendix would have a crown width of 10 feet, a river-side slope of 1 vertical on 2-1/2 horizontal, and a land-side slope of 1 on 2. Except for the material required for an impervious blanket, a suitable mixture consisting of gravel, sand, and silt, adjacent to the site, is available for the construction of the embankment. Material suitable for the impervious blanket is available within a distance of one mile. Some seepage would be expected through the foundation

but would be controlled by a pervious filter blanket and toe drains.

44. Concrete wall and stop-log structure. - Concrete walls would be used in the restricted space west of Elmwood Avenue. The walls would be of the cantilever type and would not exceed a height of 19 feet above the ground. Adequate control of underground seepage would be effected by extending the shear key into a relatively impervious material and providing toe drains. A concrete stop-log structure with a removable center support would be provided at Elmwood Avenue.

45. Riprap protection. - The sections of levee between the railroad embankment and Perkins Avenue would be protected against scour with hand-placed riprap carried to within 2 feet of the top of the levee.

46. Drainage and pumping facilities. - A pumping plant with a capacity of 75 cubic feet per second would handle the storm run-off and levee seepage. It would be located at the levee about 100 feet east of Elmwood Avenue. Flow in the existing ditch west of the railroad and in the highway drain under Elmwood Avenue would be intercepted and carried to the pumping station. An intercepting sewer along Second and Amber Streets and thence along the levee would be built to handle storm run-off and levee seepage in the area east of Elmwood Avenue.

47. Estimate of cost. - The total Federal investment for the Cranston Levee would include the cost of construction of the levee and pumping plant. The acquisition of lands for rights-of-way, the settlement of damage claims, and the construction of intercepting sewers would be non-Federal obligations. All costs would be amortized over a period of 50 years except for the pumping plant and equipment, which would be written off in 20 years. Maintenance and operation have been computed at 2 percent of the total cost of the pumping plant and 1/2 of 1 percent of the total cost of the construction of the levee. Estimates of costs

for two levee grades have been computed and are presented in the following table. Estimate I is for the levee grade as established for Cranston Levee with Warwick Levee built on the opposite bank of the river. Estimate II is for the levee grade governed by a levee on the Cranston side of the river only. Both estimates are based on the prior construction of the Broad Street Improvement.

Cost Estimate I

Cranston Levee with Warwick Levee and Broad Street Improvement in place

Item No.	Item	Quantity	Unit cost	Amount	Total
1.	Levee construction				
	Clearing	18 acres	$150.00	$ 2,700	
	Stripping	11,500 c. y.	0.50	5,800	
	Excavation(cut-off trench)	9,300 c. y.	0.25	2,300	
	Embankment, earth	110,900 c. y.	0.55	61,000	
	Riprap	3,490 c. y.	6.00	20,900	
	Concrete, Class A	2,970 c. y.	15.50	46,000	
	Reinforcing steel	297,000 lbs.	0.05	14,900	
	Excavation and backfill	5,300 c. y.	0.40	2,100	
	Drains, concrete walls	950 l. f.	1.90	1,800	
	Drains, earth levees	4,200 l. f.	3.25	13,700	
	Steel sheet-piling	4,000 s. f.	1.25	5,000	
				176,200	
	Contingencies		20%	35,200	
				211,400	
	Engineering and overhead		15%	31,600	
	Total				$243,000
2.	Drainage and pumping facilities				
	Pumping plant	1-75 c.f.s.	L.S.	63,000	
	Intercepting sewer (22")	1,100 l. f.	5.70	6,300	
	Intercepting sewer (30")	1,300 l. f.	8.00	10,400	
	Intercepting sewer (36")	550 l. f.	8.90	4,900	
	Intercepting sewer (39")	950 l. f.	9.20	8,700	
				93,300	
	Contingencies		20%	18,700	
				112,000	
	Engineering and overhead		15%	17,000	
	Total				129,000
3.	Rights-of-way and damages				
	Land		L.S.	11,500	
	Damages		L.S.	13,500	
				25,000	
	Legal, overhead, and general expense		20%	5,000	
	Total				30,000
4.	Grand total capital cost				402,000

5. Total annual cost

	Cost	Total
(a) Federal investment:		
Levee construction $176,200 by 1.38	$243,000	
Pumping station 63,000 by 1.38	87,000	
Total Federal investment	330,000	
(b) Federal annual carrying charge:		
Interest $330,000 by .035	11,550	
Amortization of obsolescence and depreciation:		
Fixed parts $176,200 by 1.38 by .0076	1,850	
Movable parts 63,000 by 1.38 by .0354	3,080	
Total Federal annual carrying charge ..		$16,480
(c) Non-Federal investment:		
Land and damages $25,000 by 1.20	30,000	
Drainage 30,300 by 1.38	42,000	
Total non-Federal investment	72,000	
(d) Non-Federal annual carrying charge:		
Interest $72,000 by .045	3,240	
Amortization of obsolescence and depreciation $72,000 by .0056	400	
Tax loss $11,500 by 1.20 by .02	280	
Maintenance and operation:		
Levees and drainage $206,500 by 1.38 by .005	1,460	
Pumping station $63,000 by 1.38 by .02 ...	1,740	
Total non-Federal annual carrying charge		7,120
Total annual cost		23,600

Cost Estimate II

Cranston Levee alone with Broad Street Improvement in place

Item No.	Item	Quantity	Unit cost	Amount	Total
1.	Levee construction				
	Clearing	19 acres	$150.00	$ 2,800	
	Stripping	8,100 c. y.	0.50	4,100	
	Excavation(cut-off trench)	10,100 c. y.	0.25	2,500	
	Embankment, earth	69,300 c. y.	0.55	38,100	
	Riprap	2,350 c. y.	6.00	14,100	
	Concrete, Class A	2,180 c. y.	15.50	33,800	
	Reinforcing steel	218,000 lbs.	0.05	10,900	
	Excavation and backfill	4,000 c. y.	0.40	1,600	

(continued)

Item No.	Item	Quantity	Unit cost	Amount	Total
	Drains, concrete walls	950 l. f.	$1.90	$ 1,800	
	Drains, earth levees	4,300 l. f.	3.25	14,000	
	Steel sheet-piling	4,000 s. f.	1.25	5,000	
				128,700	
	Contingencies		20%	25,700	
				154,400	
	Engineering and overhead		15%	23,600	
	Total				$178,000
2.	Drainage and pumping facilities				
	Pumping plant	1-75 c.f.s.	L.S.	63,000	
	Intercepting sewer (22")	1,100 l. f.	5.70	6,300	
	Intercepting sewer (30")	1,300 l. f.	8.00	10,400	
	Intercepting sewer (36")	550 l. f.	8.90	4,900	
	Intercepting sewer (39")	950 l. f.	9.20	8,700	
				93,300	
	Contingencies		20%	19,000	
				112,300	
	Engineering and overhead		15%	16,700	
	Total				129,000
3.	Rights-of-way and damages				
	Land		L.S.	11,400	
	Damages		L.S.	13,300	
				24,700	
	Legal, overhead, and general expense		20%	4,300	
	Total				29,000
4.	Grand total capital cost				336,000
5.	Total annual cost			Cost	Total
	(a) Federal investment:				
	Levee construction $128,700 by 1.38			$178,000	
	Pumping station 63,000 by 1.38			87,000	
	Total Federal investment			265,000	
	(b) Federal annual carrying charge:				
	Interest $265,000 by .035			9,280	
	Amortization of obsolescence and depreciation:				
	Fixed parts $128,700 by 1.38 by .0076			1,340	
	Movable parts 63,000 by 1.38 by .0354			3,080	
	Total Federal annual carrying charge ..				$13,700
	(c) Non-Federal investment:				
	Land and damages $24,700 by 1.20			29,000	
	Drainage 30,300 by 1.38			42,000	
	Total non-Federal investment			71,000	

(d) Non-Federal annual carrying charge:

Interest $71,000 by .045	$3,200	
Amortization of obsolescence and depreciation $71,000 by .0056	400	
Tax loss $11,400 by 1.20 by .02	270	
Maintenance and operation:		
Levees and drainage $159,000 by 1.38 by .005	1,100	
Pumping station 63,000 by 1.38 by .02	1,740	
Total non-Federal annual carrying charge		$ 6,710
Total annual cost		20,410

BROAD STREET IMPROVEMENT

48. General. - The Broad Street Bridge crosses the Pawtuxet River just above its mouth. A small dam, known as the Broad Street or Pawtuxet Dam, is located 75 feet upstream from this bridge. The bridge and dam together form a water-stage control for the lower three miles of the Pawtuxet River, the former at high flows and the latter at lower flows. The plan of improvement provides for lowering the dam and installing automatic flashboards, increasing the size of the bridge opening, and excavating a small quantity of ledge rock between the dam and the bridge. Such a plan would lower flood stages for the length of the river controlled.

49. Existing legislation. - The Broad Street or Pawtuxet Dam is maintained by the City of Providence in accordance with the 1915 Rhode Island Water Act which authorizes the construction of Scituate Reservoir for water supply. The pertinent paragraph of Section 6 of the above Act reads as follows:

> "Before said City of Providence diverts any of said waters for said water supply for said city, it shall build a masonry dam across the Pawtuxet River, in the village of Pawtuxet, on the same site and of the same height as the present dam there situated, and shall so maintain the same."

50. Description of flooded area. - The flooded area affected includes 80 acres of farm land, two large industrial plants, four recreational areas and clubs, an extensive state nursery, several business blocks, and 200 homes, all located in the Cities of Warwick and Cranston.

51. Flood losses. - The direct losses within the area affected by the improvement amounted to $12,400 in the March 1936 flood and $79,000 in the July 1938 flood. The record flood of February 1886 reached a peak stage approximately 6 feet higher than the 1938 flood, but no records of the losses are available. It is estimated that a damage of $238,000 would result if a flood reached this height today. Average annual direct losses have been computed to be $16,430. Indirect losses are estimated as approximately equal to the direct losses. A total depreciation of $57,200, resulted from the recent floods of 1936 and 1938. The annual depreciation loss is estimated to be $2,066 for the area.

52. Dam and appurtenant works. - The existing dam is a concrete overflow section with a crest elevation of 5.2 feet above mean sea level. It spans the river in a zig-zag course to tie into two insular projections of ledge. The crest length is 170 feet. The portion of the existing dam above elevation 1.0 foot would be removed and in its place an overflow dam of concrete would be constructed with a crest elevation 3.0 feet above mean sea level and a length of 230 feet. The overflow section would be keyed into rock, and would have a vertical upstream face,

a rounded crest, and a downstream face sloped to approximately the nappe of freely flowing water at full head. The average height would be 7 feet and the base width would be 17 feet. The existing pool level would be maintained by temporary flashboards supported by pins designed to fail when the pool elevation reached 7.2 feet. All material in the channel below the dam projecting or lying above elevation -3.0 feet would be removed. A plan of the proposed work is shown on Plates 8 and 9 of the Appendix.

53. Highway bridge. - The Broad Street Bridge over the Pawtuxet River was originally a twin-arch stone masonry bridge 30 feet wide. In 1933 the State widened the bridge on the upstream side to provide for a 40-foot roadway and two 9-foot sidewalks. The arches and the retaining wall of the new construction are of reinforced concrete. A stone masonry facing has been applied to retain the architectural features of the original bridge. Under this plan of improvement the waterway would be increased 50 percent by constructing a third arch at the south end of the bridge. Construction similar to that used for the widening would be used. According to plans prepared for the 1933 state contract, ledge is available for the foundation of the third arch. The proposed plan is shown on Plate 8 of the Appendix.

54. Concrete retaining wall. - A concrete wall would be constructed upstream and downstream from the bridge to retain the existing fill on the right bank of the Pawtuxet River. The alignment of the proposed wall is shown on Plate 8 of the Appendix. The wall would be of the cantilever type with a maximum height of 23 feet in the vicinity of the bridge. The overall length of the wall would be 270 feet, beginning above the dam and extending to the boat-well off Pawtuxet Cove. Rock foundation is available above the bridge, but below the bridge the ledge surface drops and the wall would be placed on timber piles.

55. Estimate of cost. - The total Federal investment for the Broad Street Improvement would include all construction costs. The acquisition of lands for rights-of-way and the settlement of damage claims would be non-Federal obligations. The cost of the retaining wall and the bridge would be written off at the rate of 1 percent per annum. The cost of maintenance is computed at 1 percent per annum plus the cost of annual replacements of flashboards. All other costs would be amortized in 50 years. The estimated cost of the proposed channel improvement at Broad Street is given in the following table:

Cost Estimate for the Broad Street Improvement

Item No.	Item	Quantity	Unit cost	Amount	Total
1.	Construction cost				
	a. Retaining wall				
	Rock excavation	600 c.y.	$ 3.00	$ 1,800	
	Earth excavation	4,800 c.y.	0.50	2,400	
	Backfill	2,700 c.y.	0.25	700	
	Concrete, Class A	680 c.y.	15.00	10,200	
	Reinforcing steel	68,000 lbs.	0.05	3,400	
	Gravel drain	120 c.y.	2.00	200	
	Timber bearing piles	2,200 l.f.	0.80	1,800	
				20,500	
	Contingencies		20%	4,000	
				24,500	
	Engineering and overhead		15%	3,500	
	Total				$28,000
	b. Enlarging Pawtuxet Bridge				
	Bridge excavation	3,000 c.y.	4.00	12,000	
	Rock excavation	550 c.y.	10.00	5,500	
	Concrete, Class A	250 c.y.	25.00	6,300	
	Concrete, Class B	240 c.y.	15.00	3,600	
	Sidewalk	170 s.y.	1.50	300	
	Reinforcing steel	25,000 lbs.	0.05	1,300	
	Ashlar masonry	30 c.y.	65.00	2,000	
	Gravel fill	600 c.y.	1.50	900	
	Bituminous paving	390 s.y.	2.00	800	
	Earth fill	1,000 c.y.	0.60	600	
	Bridge rail	100 l.f.	6.50	700	
				34,000	
	Contingencies		20%	6,800	
				40,800	
	Engineering and overhead		15%	6,200	
	Total				47,000

Item No.	Item	Quantity	Unit cost	Amount	Total
c.	Dam and channel excavation				
	Remove existing dam	125 c.y.	$5.00	$ 600	
	Rock excavation	2,050 c.y.	5.00	10,200	
	Concrete, Class B	590 c.y.	10.00	5,900	
	Flashboards	230 l.f.	1.75	400	
				17,100	
	Contingencies		20%	3,500	
				20,600	
	Engineering and overhead		15%	3,400	
	Total				$24,000
2.	Rights-of-way and damages				
	Land		L.S.	800	
	Damages		L.S.	3,300	
				4,100	
	Legal, overhead, and general expense		20%	900	
	Total				5,000
3.	Grand total capital cost				104,000
4.	Total annual cost			Cost	Total
	(a) Federal investment:				
	Dam construction $17,100 by 1.38			$24,000	
	Retaining walls 20,500 by 1.38			28,000	
	Bridge construction $34,000 by 1.38			47,000	
	Total Federal investment			99,000	
	(b) Federal annual carrying charge:				
	Interest $99,000 by .035			3,470	
	Amortization of obsolescence and depreciation:				
	Concrete walls and bridge $54,500 by 1.38 by .01			750	
	Channel and dam $17,100 by 1.38 by .0076 ..			180	
	Maintenance and operation:				
	Bridge, dam, walls $71,600 by 1.38 by .01 .			990	
	Flashboards annual replacement			400	
	Total Federal annual carrying charge ...				$ 5,790
	(c) Non-Federal investment:				
	Land and damage $4,100 by 1.20			5,000	
	Total non-Federal investment			5,000	
	(d) Non-Federal annual carrying charge:				
	Interest $5,000 by .045			220	
	Amortization of land and damage $4,100 by 1.20 by .0056			30	
	Loss of taxes $800 by 1.20 by .02			20	
	Total non-Federal annual carrying charge				270
	Total annual cost				6,060

CRANSTON CUT-OFF

56. General. - The Cranston Cut-off would be a new channel, starting 2200 feet below the Elmwood Avenue Bridge, and cutting across the neck of land protruding from the left side of the river. It would be 1600 feet long and would eliminate 3400 feet of the existing channel. The area protected would include the land on both sides of the river extending from the upper end of the Cut-off to the Pettaconsett Dam 1-1/2 miles upstream from Elmwood Avenue. Protection would result from a lowering of flood stages and would not be complete.

57. Description of flooded area. - The flooded area which would receive partial protection from the cut-off includes one large modern textile machinery plant, a few business blocks on Elmwood Avenue, and several homes, located in Cranston and Warwick.

58. Flood losses. - The direct loss within the area affected by the improvement amounted to $8,800 in the March 1936 flood and $71,000 in the July 1938 flood. The larger loss in 1938 is accounted for by the increased losses of the textile machinery company. The maximum flood of record, that of February 1886, reached a peak stage approximately 6 feet higher than the 1938 flood but no records of the losses are available. If a flood should reach this height today, it is estimated that a damage of $186,100 would result. The average annual direct losses have been computed to be $9,380. Indirect losses are estimated as approximately equal to the direct losses. The annual depreciation loss is estimated to be $1100 for the area.

59. Alignment. - The channel alignment would be an approximate straight-line extension of the channel at the upstream end, which is 2200 feet below the Elmwood Avenue Bridge. It would curve slightly to the left at the lower end to rejoin the existing channel on a tangent. The alignment is shown on Plate 5 of the Appendix.

60. Geology. - Impervious silt strata about 25 feet thick underlie the entire area at a depth of about 12 feet. These strata are overlain with numerous stratifications of coarser material ranging from moderately fine sand to pervious sand and gravel. The upper portions of this overburden contain minor amounts of organic and vegetable material. Rock is deeply buried, occurring at a depth of at least 50 feet.

61. Excavation. - The channel would have a bottom width of 120 feet with side slopes of 1 vertical on 2 horizontal, and would be excavated in earth to the depth of the existing river bed. The channel would follow an existing swale with an average cut of 10 feet, except at the upper end where the maximum cut would be 16 feet. The total volume of earth excavation required would be 77,000 cubic yards. This material would be spoiled along the north bank of the channel and in the existing channel eliminated by this cut-off.

62. Estimate of cost. - The total Federal investment for the Cranston Cut-off would include all construction costs. The acquisition of lands for rights-of-way and the settlement of damage claims would be non-Federal obligations. The estimated value of land includes, in addition to the area required at the channel, the area in the island that would be created by the proposed plan. All costs have been amortized over a period of 50 years. Maintenance has been computed at 1 percent of the total cost of the project. The following table gives the estimated cost of the Cranston Cut-off:

(Table on following page)

Cost Estimate for Cranston Cut-off

Item No.	Item	Quantity	Unit cost	Amount	Total
1.	Construction				
	Clearing	9 acres	$150.00	$ 1,300	
	Channel excavation	77,000 c. y.	0.50	38,500	
				39,800	
	Contingencies		20%	8,000	
				47,800	
	Engineering and overhead		15%	7,200	
	Total				$55,000
2.	Rights-of-way and land				
	Land		L.S.	8,600	
	Improvements		L.S.	8,300	
				16,900	
	Legal, overhead, and general expense		20%	3,100	
	Total				20,000
3.	Grand total capital cost				75,000
4.	Annual cost			Cost	Total
	(a) Federal investment:				
	Construction cost $39,800 by 1.38			$55,000	
	Total Federal investment			55,000	
	(b) Federal annual carrying charge:				
	Interest $55,000 by .035			1,920	
	Amortization of obsolescence and depreciation:				
	Channel $39,800 by 1.38 by .0076			420	
	Maintenance and operation $55,000 by .01 ..			550	
	Total Federal annual carrying charge ..				$ 2,890
	(c) Non-Federal investment:				
	Land and damage $16,900 by 1.20			20,000	
	Total non-Federal investment			20,000	
	(d) Non-Federal annual carrying charge:				
	Interest $20,000 by .045			900	
	Amortization of land and damage $16,900 by 1.20 by .0056			110	
	Loss of taxes $16,900 by 1.20 by .02			400	
	Total non-Federal annual carrying charge				1,410
	Total annual cost				4,300

PONTIAC DIVERSION

63. General. - The Pontiac Diversion would provide a flood channel from Pontiac to Apponaug Cove. During floods, all flows in excess of safe channel capacities downstream would be diverted through this channel. Hence, the lower Pawtuxet would receive complete protection from flood waters originating on 195.4 square miles of the total 230.4 square miles of drainage area in the Pawtuxet Watershed. Stream flow would be excluded from the diversion channel at all times except during flood.

64. Design criteria. - The Pontiac Diversion channel has been designed to carry the peak discharge of the maximum predicted flood, 29,000 cubic feet per second, with a freeboard of three feet. The Stoney-type gates in the diversion dam would have a capacity of 8,000 cubic feet per second at the maximum flow line. This would be adequate to maintain the normal flow of the stream without affecting water levels upstream.

65. Alignment. - The diversion dam across the Pawtuxet River would be located 200 feet west of the highway bridge at Pontiac. The approach section of the diversion channel would be 2,800 feet upstream from the dam, at a bend where the river flows nearest to East Avenue. A gate structure would admit flood flows into the channel, which would cross East Avenue and thence follow a winding course through the depressions in the terrain to that portion of Gorton's Pond on the west side of the highway embankment. Below the pond, the channel would continue for a distance of 1,000 feet between the Apponaug Mill and the buildings fronting on Highways Nos. 5 and 1. It would then turn east, cross Highway No. 1, and empty into the Apponaug River. Flow through the pond would be confined by earth levees wherever needed, and would discharge over a spillway into the channel at its southern end. The normal operation of the pond would be maintained by the installation of gates. The plan of the proposed diversion channel is shown on Plate 10 of the Appendix.

66. Geology. - The proposed diversion channel would be excavated in a glacial formation of sand and gravel which forms the divide between the Pawtuxet and Apponaug Rivers. Subsurface explorations indicate an irregular bedrock surface lying at a depth greater than 50 feet at the northerly and southerly ends of the channel, and rising to about 15 feet below the ground surface near Station 75+00.

67. Diversion dam. - The diversion dam across the Pawtuxet River would be a rolled-fill earth dam with a reinforced concrete gate section located in the present river channel. The total length of the dam would be 1,900 feet, of which 1,300 feet would be a low dike across the terrace above the left bank of the river. The elevation of the top of the dam would be 46.0 feet above mean sea level, and 25 feet above the bed of the stream. The dam would have a top width of 20 feet, side slopes of 1 on 3, and would contain an impervious core from top to bottom keyed into a cut-off trench along the axis of the dam. The dike would have similar dimensions but would be built of random material. The upstream slope of the dam and dike would be protected against wave action by a facing of riprap. Random material is available at the site and from the channel excavation. Impervious material is available within a distance of one mile from the dam. The gate section, containing three Stoney-type gates 15 feet wide and 8.5 feet high, would be founded on a compacted mixture of gravel, sand, and silt. Steel sheet-pile cut-offs would be provided to prevent piping, and the channel would be paved with riprap both upstream and downstream from the structure to prevent undermining.

68. Channel. - The entire length of the channel would be lined with reinforced concrete 8 inches thick. A berm 10 feet wide would be provided at the top of the lining, above which the material would be trimmed back on a 1 on 1-1/2 slope. The upper section of the channel, 4,200 feet

long, would have a bottom width of 100 feet and the sides of the lining would be carried up on a 1 on 1-1/4 slope to 3 feet above the maximum water surface. The lower channel would be 1,300 feet long, and would have a bottom width of 50 feet with the sides carried up on a 1 on 1 slope to 4 feet above the maximum water surface.

69. Appurtenant works. - The special structures would include a gate structure at the entrance of the channel, a weir at the outlet of the pond, and about 3,600 feet of levees around the lower end of the pond.

a. Gate structure. - The gate structure would be of reinforced concrete construction 140 feet wide and 24 feet high. It would contain 8 Stoney-type gates, each 15 feet wide and 8.5 feet high, operated from above by a gantry crane.

b. Weir. - The elevation of the weir crest at Gorton's Pond would be 15 feet above mean sea level. The weir would be a concrete ogee section 200 feet long with the crest 13 feet above the bottom of the channel into which it discharges. Concrete abutments would key it into the proposed levees around the lower end of the pond.

c. Gorton's Pond Levee. - The maximum height of the levees would be 20 feet. They would have a 10-foot crown width and side slopes not steeper than 1 vertical on 2 horizontal. Riprap would be provided to protect the face of the levee in the vicinity of the spillway weir. Also, the approach channel and a portion of the pond area near the outlet of the channel would be paved with riprap.

70. Highway bridges. - Bridges would be provided at East Avenue and State Highways Nos. 117 and 1, the three important roads which the channel would cross. The East Avenue bridge would be a steel arch bridge, 30 feet wide with a 150-foot central span and short overhanging spans. Concrete covered steel girder bridges 50 feet wide with a single span of 90 feet

would be used to carry Highways Nos. 117 and 1 over the channel. On Highway No. 1 the proposed bridge would replace an existing bridge of much smaller capacity. Traffic on Highways Nos. 1 and 117 would have to be maintained while building the bridges. Traffic on East Avenue could be detoured.

71. Estimate of cost. - The estimate of annual cost has been computed on the basis that non-Federal interests would bear 25 percent of the total capital cost of the project, not to exceed the sum of $347,500. The entire project would be amortized in 50 years, except for concrete structures and lining, highway bridges, and gates and machinery. The annual charge for amortization for concrete and the bridges has been computed at 1 percent and for gates and machinery at 3 percent of their estimated cost. Maintenance has been computed at 1 percent annually for concrete works and bridges, and at 3 percent annually for gates. A lump sum of $500 per annum has been provided for maintenance of the diversion dam and a lump sum of $2,000 per annum has been allowed for an operator, standby power, and expendable supplies. The estimate of cost is shown in the following table:

(See table on following page)

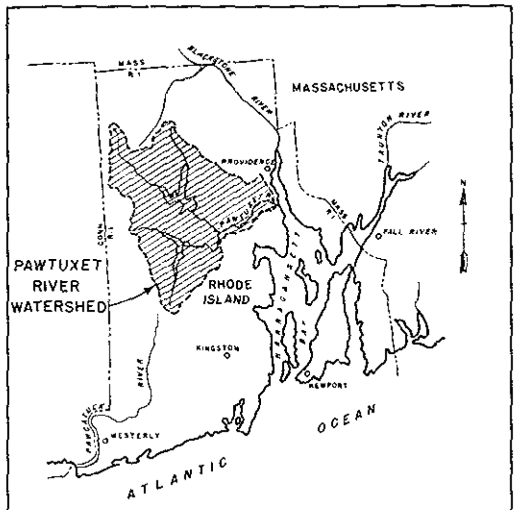
Cost Estimate for Pontiac Diversion

Item No.	Item	Quantity	Unit cost	Amount	Total
1.	Construction cost				
	a. Diversion channel				
	Clearing	62 acres	$150.00	$ 9,300	
	Stripping	6,300 c. y.	0.50	3,200	
	Embankment, earth levees	47,800 c. y.	0.30	14,300	
	Riprap	5,690 c. y.	5.00	28,400	
	Channel excavation	810,600 c. y.	0.25	202,600	
	Rock excavation	15,300 c. y.	2.00	30,600	
	Concrete, Class A	1,470 c. y.	15.50	22,800	
	Concrete, Class B	2,080 c. y.	12.00	25,000	
	Concrete, channel lining	94,720 s. y.	3.00	284,200	
	Reinforcing steel	147,000 lbs.	0.05	7,300	
	Steel sheet-piling	14,400 s. f.	1.25	18,000	
	Excavation, concrete structure	4,600 c. y.	1.00	4,600	
	Tile drains	1,000 l. f.	1.00	1,000	
	Gates and machinery		L.S.	45,000	
				696,300	
	Contingencies		20%	139,300	
				835,600	
	Engineering and overhead		15%	125,400	
	Total				$961,000
	b. Diversion dam				
	Clearing	8 acres	250.00	2,000	
	Stripping	5,400 c. y.	0.50	2,700	
	Stream control		L.S.	10,000	
	Embankment, placing	54,600 c. y.	0.15	8,200	
	Embankment, borrow	9,800 c. y.	0.35	3,400	
	Excavation	3,800 c. y.	0.30	1,200	
	Rock drain	900 c. y.	2.50	2,200	
	Riprap	1,100 c. y.	5.00	5,500	
	Concrete, Class A	1,290 c. y.	15.50	20,000	
	Reinforcing steel	129,000 lbs.	0.05	6,400	
	Steel sheet-piling	2,700 s. f.	1.25	3,400	
	Paving	500 c. y.	5.00	2,500	
	Gates and machinery		L.S.	20,000	
				87,500	
	Contingencies		20%	17,500	
				105,000	
	Engineering and overhead		15%	16,000	
	Total				121,000
2.	Highway bridges				
	Highway Route No. 1		L.S.	54,000	
	Highway Route No. 117		L.S.	54,000	
	East Avenue		L.S.	58,000	
				166,000	
	Contingencies		20%	33,200	
				199,200	
	Engineering and overhead		15%	29,800	
	Total				229,000

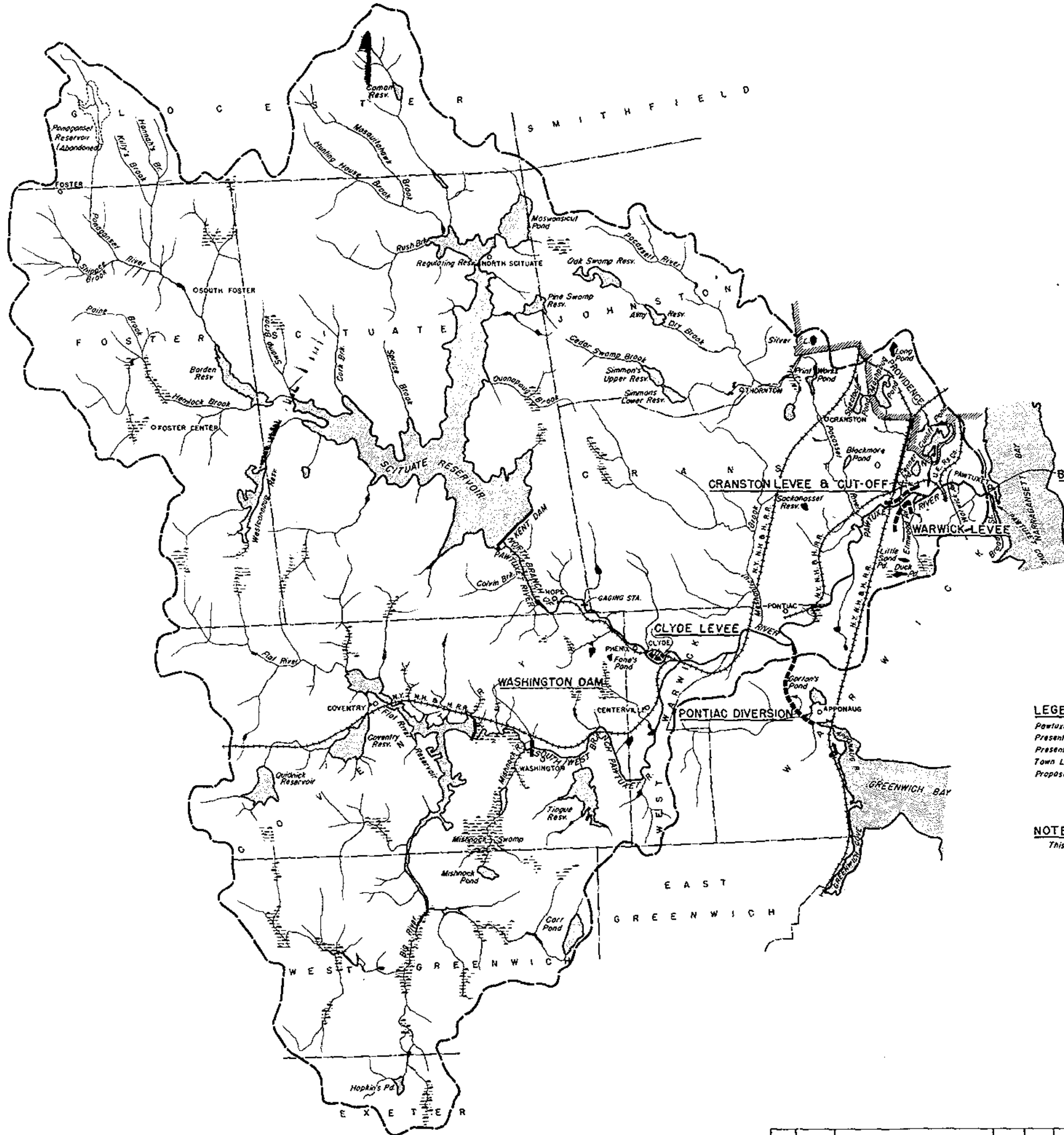
			Amount	Total
3.	Rights-of-way and damages			
	Land	L.S.	$ 45,000	
	Damages	L.S.	21,000	
			66,000	
	Legal, overhead, and general expense	20%	13,000	
	Total			$ 79,000
4.	Grand total capital cost			1,390,000

		Cost	Total
5.	Total annual cost		
	(a) Federal investment:		
	Diversion channel $696,300 by 1.38	$961,000	
	Diversion dam 87,500 by 1.38	121,000	
	Interest during construction $1,082,000 by .03 by 1/2 by 2	32,000	
	Subtotal	1,114,000	
	Local contribution $39,500 by 1.03	41,000	
	Total Federal investment	1,073,000	
	(b) Federal annual carrying charge:		
	Interest $1,114,000 by .035	38,990	
	Amortization of obsolescence and depreciation:		
	Earth embankment $62,100 by 1.38 by 1.03 by .0076	670	
	Concrete structures $656,700 by 1.38 by 1.03 by .01	9,330	
	Gates and machinery $65,000 by 1.38 by 1.03 by .03	2,770	
	Subtotal	51,760	
	Annual charges on local contribution	1,750	
	Total Federal annual carrying charge .		$ 50,010
	(c) Non-Federal investment:		
	Local contribution	39,500	
	Land and damage $ 66,000 by 1.20	79,000	
	Bridges 166,000 by 1.38	229,000	
	Interest during construction $347,500 by .045 by 1/2 by 2	15,500	
	Total non-Federal investment	363,000	
	(d) Non-Federal annual carrying charge:		
	Interest $363,000 by .045	16,340	
	Amortization of obsolescence and depreciation:		
	Contributed funds $39,500 by .0056	220	
	Land and damage $66,000 by 1.20 by .0056	440	
	Bridges $166,000 by 1.38 by .01	2,290	
	Tax loss on land $55,000 by 1.20 by .02 ...	1,320	
	Maintenance and operation		
	Earth embankment .... L.S.	500	
	Concrete structures and bridges $589,500 by 1.38 by .01	8,140	
	Gates and machinery $65,000 by 1.38 by .03	2,690	
	Attendant and supplies .... L.S.	2,000	
	Total non-Federal carrying charge		33,940
	Total annual cost		83,950

72. Plan of construction. - It would require two years to complete the construction of this project. The two bridges over Highways Nos. 1 and 117 would be built prior to the channel excavation in this area. Construction of one of these two bridges would be completed prior to beginning work on the other to interfere with traffic as little as possible. Construction of the headgates, diversion dam, and upper channel would proceed, in the order named, concurrently with the construction of the lower two bridges. During construction, stop-logs would be maintained in the gate structure at the entrance to the channel. The levees would be constructed concurrently with or following the channel excavation. Other appurtenant works and the East Avenue Bridge would be constructed after the channel is completed.



LOCATION MAP



LEGEND

Pawtuxet Watershed Boundaries shown thus
Present Large Reservoirs, Lakes, and ponds
Present Small Reservoirs, Lakes, and ponds
Town Lines shown thus
Proposed Flood Control Works

NOTES

This Map reproduced from U.S. Geological Survey Quadrangle Sheets.

KEY	DATE	REVISION (Indicated by △)	REV. BY	CK. BY	APP. BY

PAWTUXET RIVER FLOOD CONTRO

PAWTUXET RIVER WATERSHE

LOCATION MAP OF PROJECTS

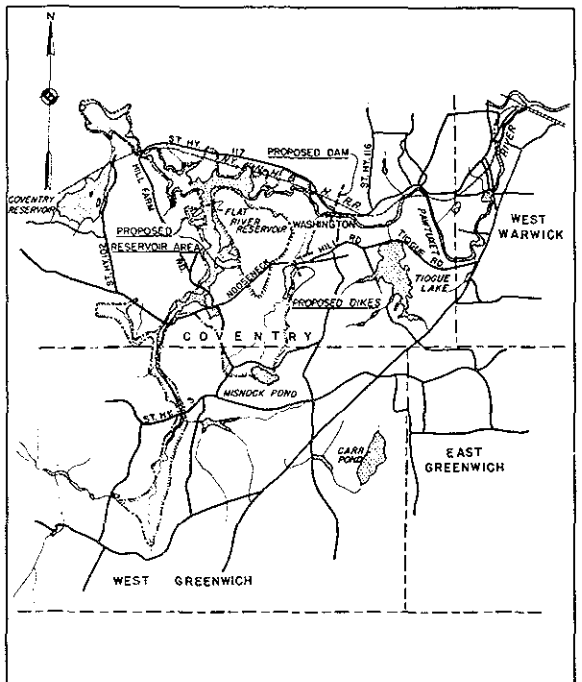
PAWTUXET RIVER RHODE ISI

IN 1 SHEETS SCALE: 1: 62,500 SHEET N

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT.

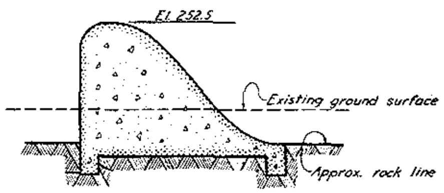
SUBMITTED: SENIOR ENGINEER HEAD, DESIGN SECTION
APPROVAL RECOMMENDED: PRINCIPAL ENGINEER CHIEF, F. C. ENGINEERING DIV.
APPROVED: DISTRICT EN

DESIGNED: W. K. Kalfleisch ASST. ENGINEER
DRAWN: J.S. TRACED: W.L. CHECKED: W.R.K.
FILE NO. PT-4- TO ACCOMPANY REP DATED: OCT. 20, 1939



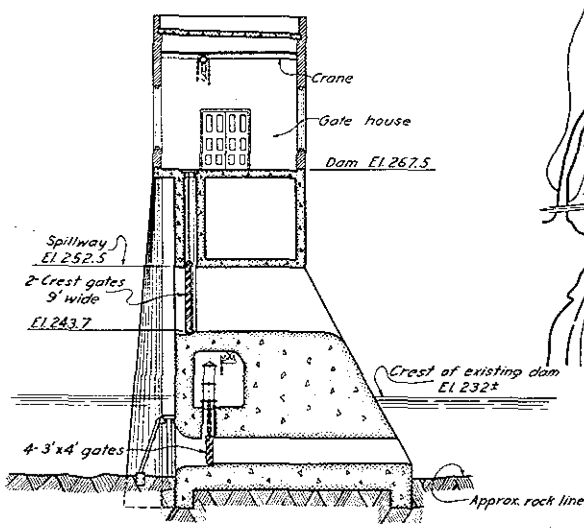
RESERVOIR AREA

SCALE: 1" = 5000'



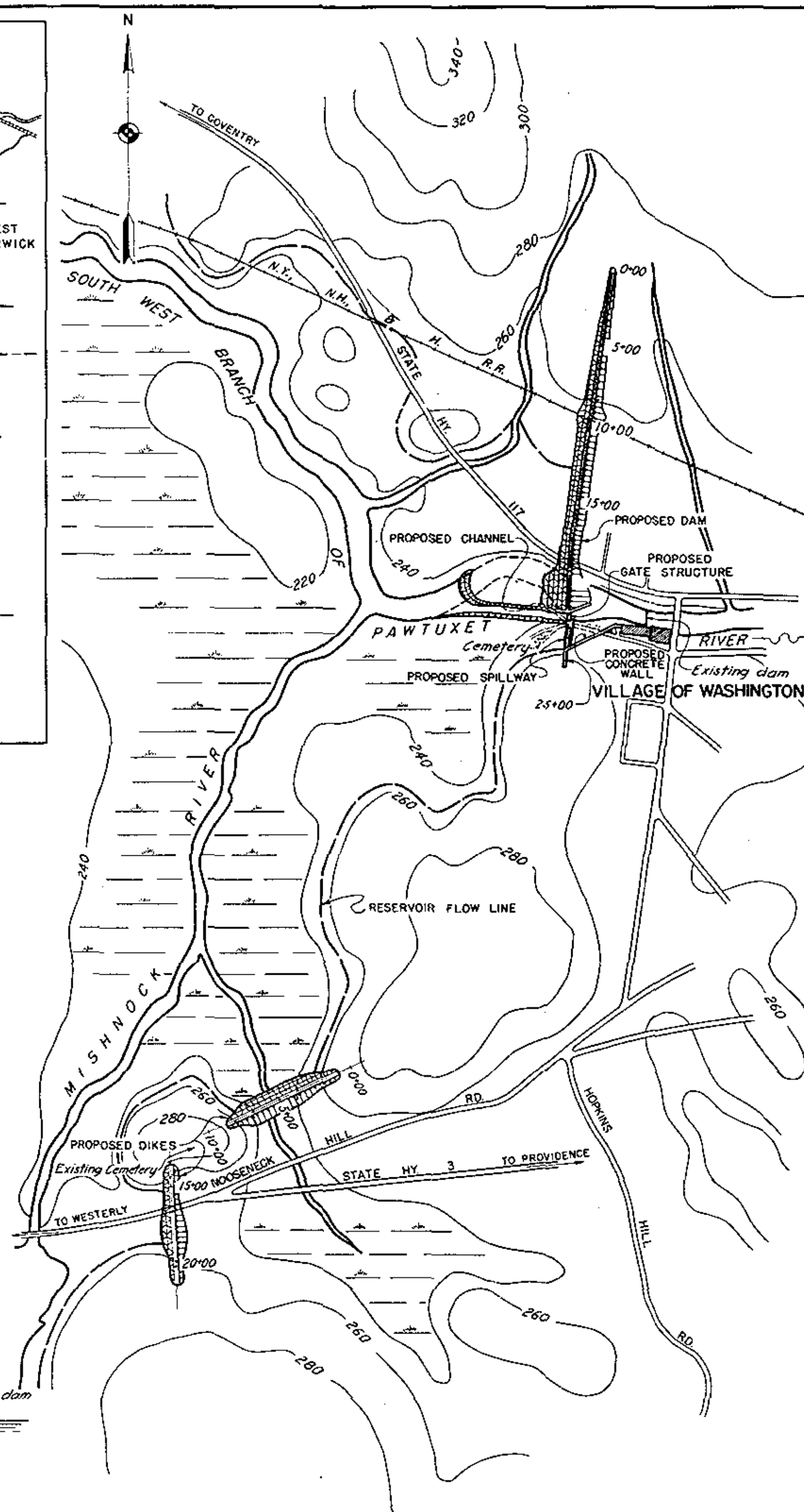
SECTION THRU SPILLWAY

SCALE: 1" = 10'-0"



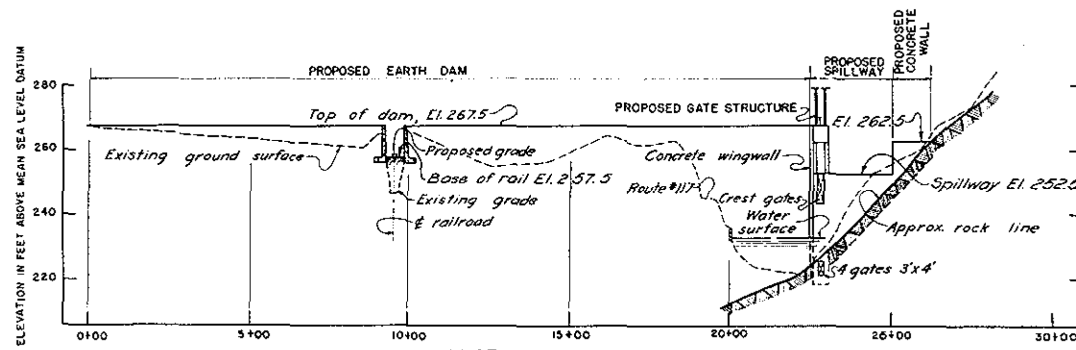
SECTION THRU GATE STRUCTURE

SCALE: 1" = 10'-0"



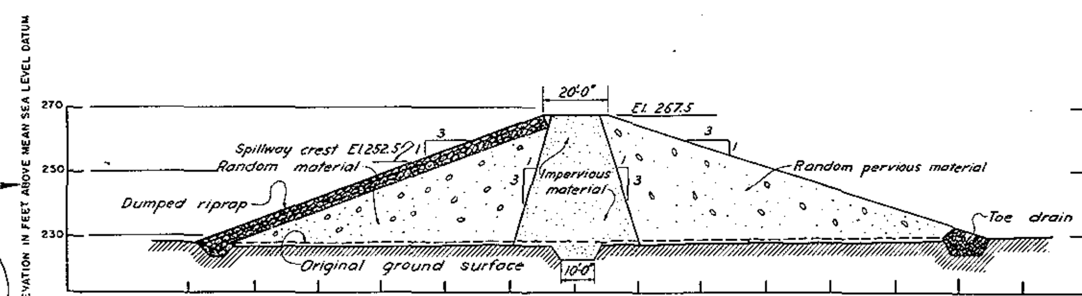
PLAN

SCALE: 1" = 400'-0"



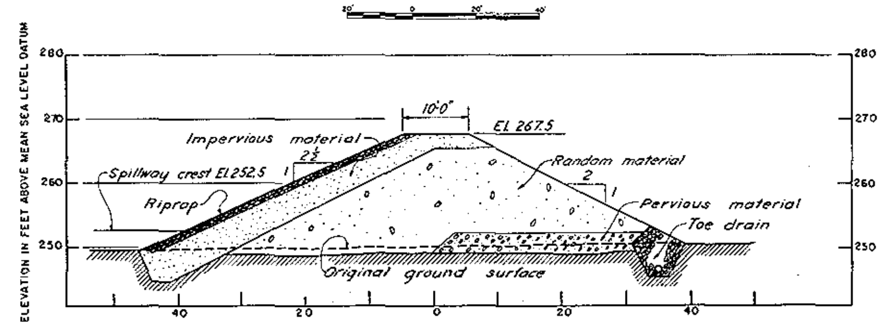
PROFILE ALONG ℄ DAM

SCALES: HOR. 1" = 200'-0" VERT. 1" = 20'-0"



SECTION THRU DAM

SCALE: 1" = 20'-0"



TYPICAL DIKE SECTION

SCALE: 1" = 10'-0"

NOTES

For location of project see Plate 1.

KEY	DATE	REVISION (indicated by △)	REV.BY	CK.BY	APP.BY

PAWTUXET RIVER FLOOD CONTROL

WASHINGTON DAM

GENERAL PLAN

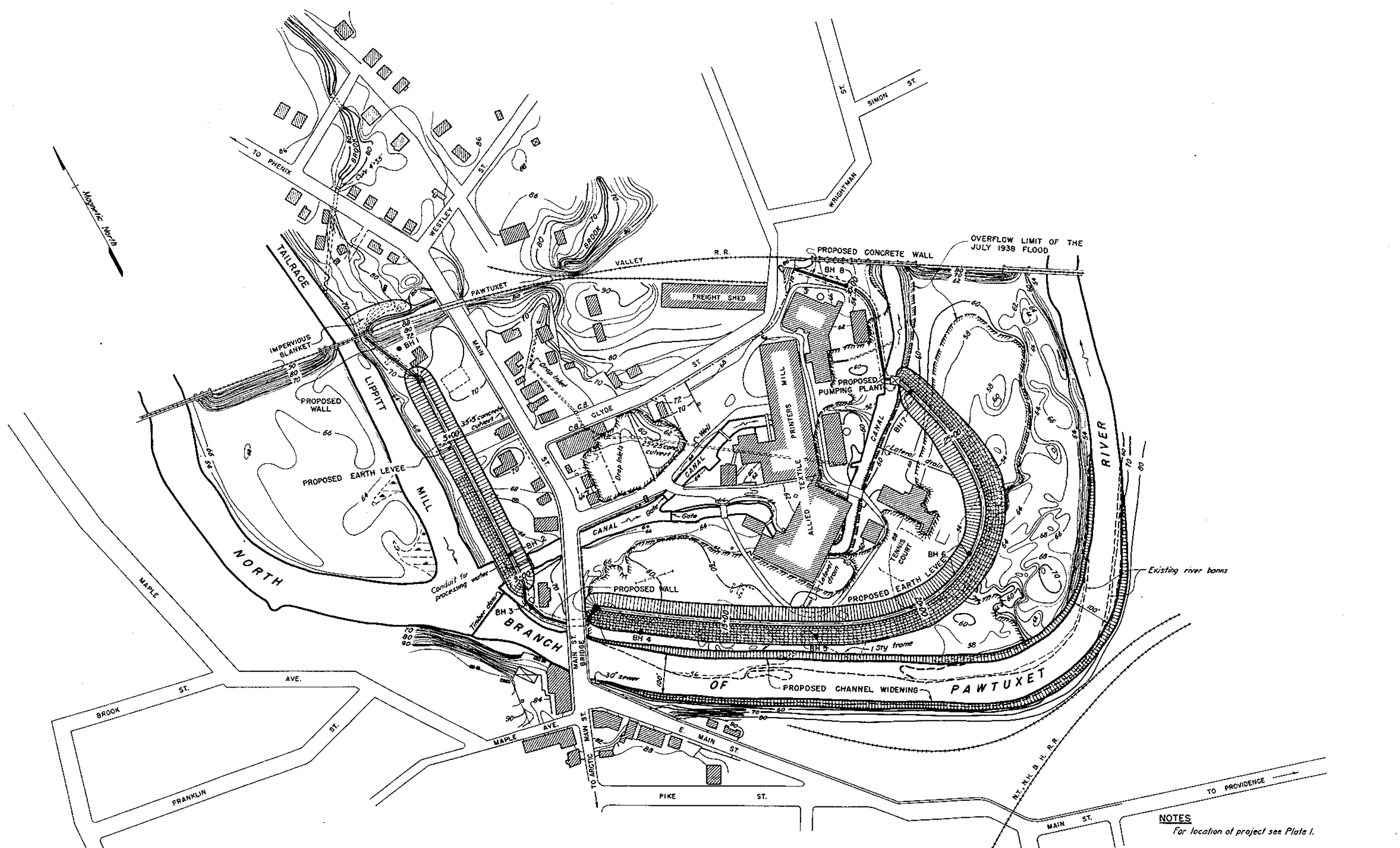
PAWTUXET RIVER RHODE ISLA

IN 1 SHEETS SCALE: 1 IN. = 400 FT. SHEET NO.

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT.

SUBMITTED: SENIOR ENGINEER, HEAD, DESIGN SECTION — APPROVAL RECOMMENDED: J. S. Burns, PRINCIPAL ENGINEER, CHIEF, F. C. ENGINEERING DIV. — APPROVED: LT. COL., CORPS OF ENGI., DISTRICT ENGINE

DESIGNED: W. R. Kahlfleisch, ASST. ENGINEER — DRAWN: J.S. TRACED: H.Z. CHECKED: — FILE NO. PT-1-10 TO ACCOMPANY REPORT DATED: OCT 20, 1939



NOTES

For location of project see Plate I.

PLAN

KEY	DATE	REVISION (Indicated by △)	REV.BY	CK.BY	AP.BY

PAWTUXET RIVER FLOOD CONTROL

CLYDE LEVEE

GENERAL PLAN

PAWTUXET RIVER — RHODE ISLA

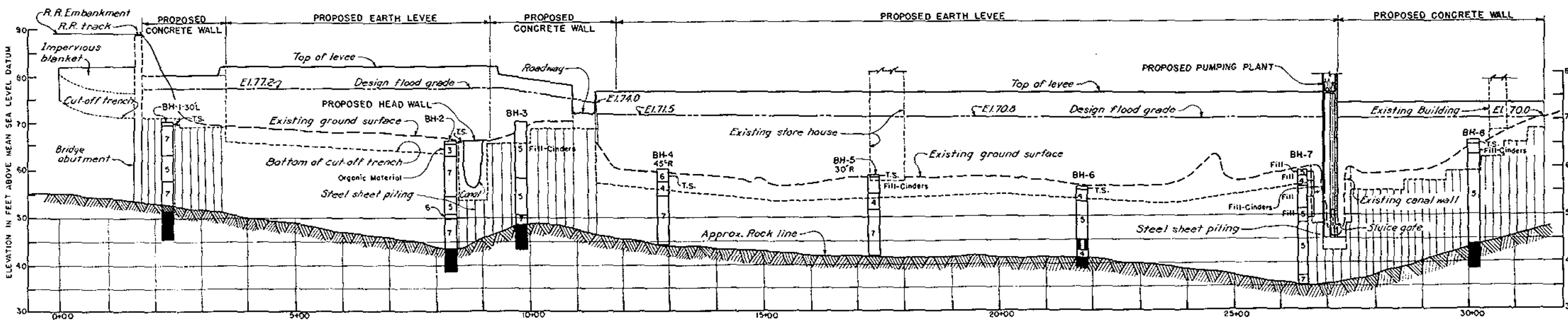
IN 2 SHEETS — SCALE: 1 IN. = 100 FT. — SHEET NO.

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT.

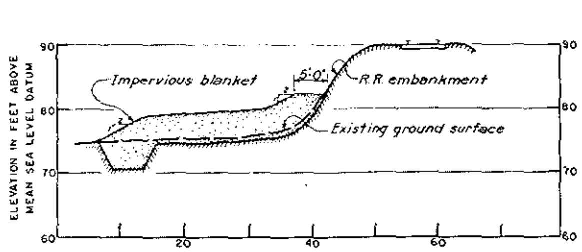
SUBMITTED: [signature] SENIOR ENGINEER, HEAD, DESIGN SECTION
APPROVAL RECOMMENDED: J. S. Bowers[?] PRINCIPAL ENGINEER, CHIEF, F. C. ENGINEERING DIV.
APPROVED: [signature] LT. COL., CORPS OF ENG. DISTRICT ENGINE

DESIGNED: W. R. Kalfleisch[?] ASST. ENGINEER
DRAWN: J.S.
TRACED: C.S.
CHECKED: F.W.L.

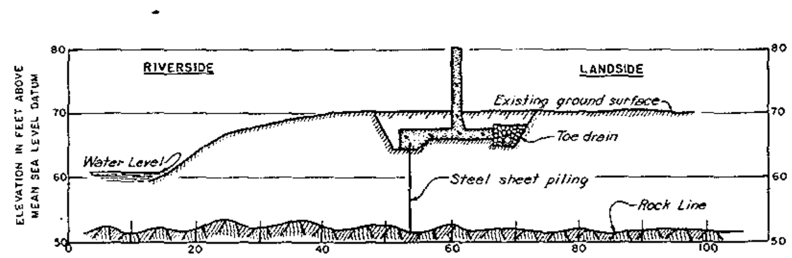
FILE NO. PT-4-1
TO ACCOMPANY REPORT
DATED: OCT. 20, 1939



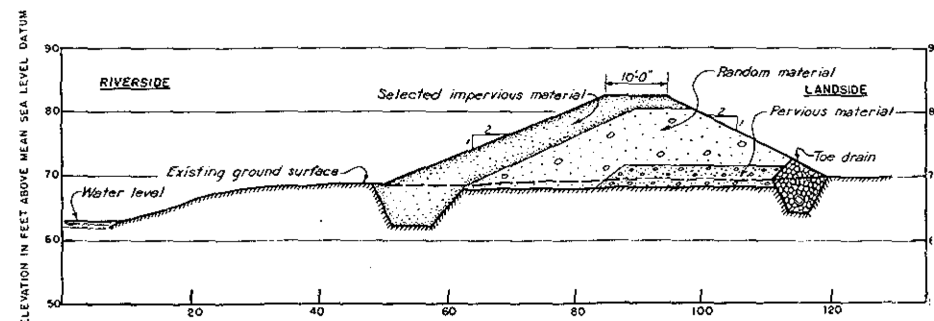
PROFILE ALONG ℄ LEVEE
SCALES: HOR. 1"=100'
VERT. 1"=10'



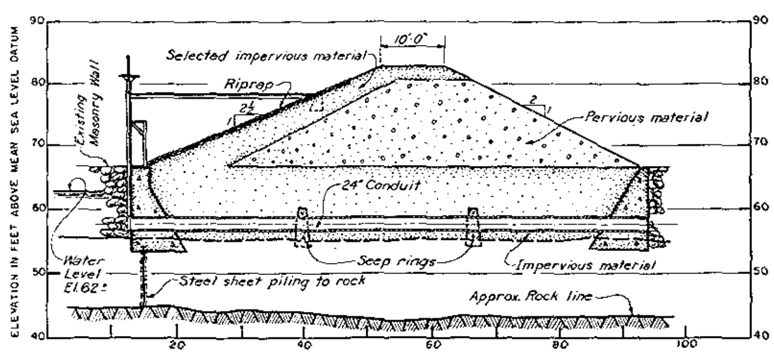
STA. 1+00
SCALE 1"=10'



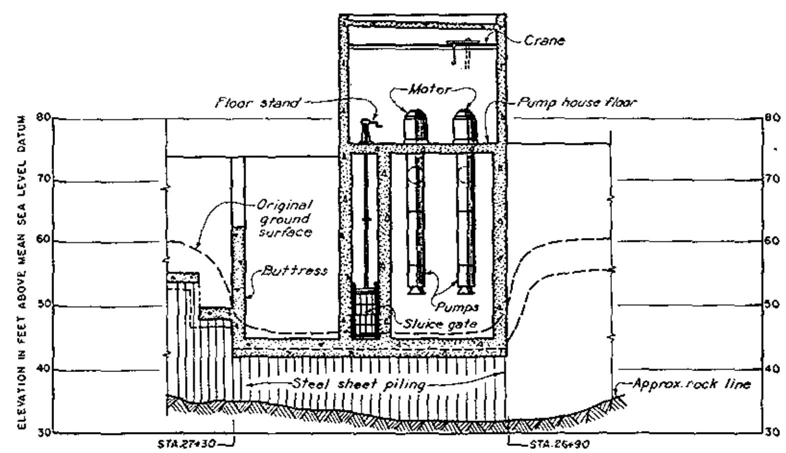
STA. 2+70
SCALE 1"=10'



STA. 5+00
SCALE 1"=10'



STA. 9+20
SCALE 1"=10'



SECTION THRU PUMPING STATION
SCALE 1"=10'

LEGEND

BH ...... Drive sample bore hole
T.S. ...... Top soil
...... Boulder
...... Solid bedrock
...... Weathered or fractured bedrock

NOTES

L-indicates landside of ℄ levee
R-indicates riverside of ℄ levee
For general notes and description of numerical classes see Plate 6.
Freeboard used in estimates is 3feet for levees and 1foot for

KEY	DATE	REVISION (Indicated by Δ)	REV.BY	CK.BY	AP.BY

PAWTUXET RIVER FLOOD CONTROL

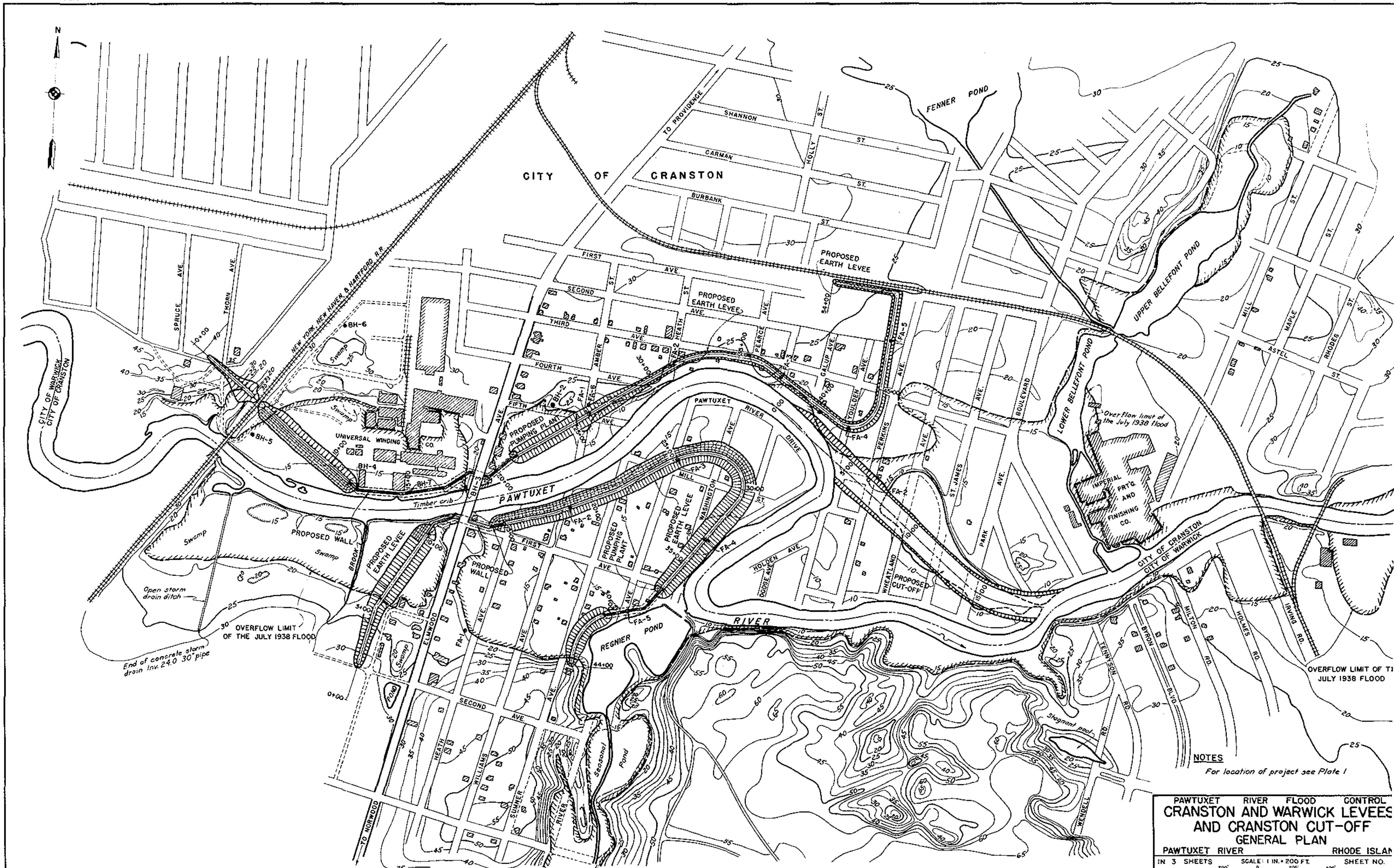
CLYDE LEVEE

PROFILE AND SECTIONS

PAWTUXET RIVER RHODE ISL
IN 2 SHEETS SCALE: 1 IN.=10 FT. SHEET NO

U. S. ENGINEER OFFICE, PROVIDENCE, R. I. OCT.

SUBMITTED: SENIOR ENGINEER HEAD DESIGN SECTION
APPROVAL RECOMMENDED: PRINCIPAL ENGINEER CHIEF F. C. ENGINEERING DIV.
APPROVED:
DESIGNED: W. R. Kallfleisch ASST. ENGINEER
DRAWN: U.S. TRACED: N.D.W. CHECKED:
FILE NO. PT-4- TO ACCOMPANY REPORT DATED OCT 20 1939



NOTES

For location of project see Plate I

PAWTUXET RIVER FLOOD CONTROL

CRANSTON AND WARWICK LEVEES AND CRANSTON CUT-OFF

GENERAL PLAN

PAWTUXET RIVER RHODE ISLAN

IN 3 SHEETS SCALE: 1 IN. = 200 FT. SHEET NO.

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT. 1

KEY	DATE	REVISION (Indicated by △)	REV.BY	CK.BY	AP.BY

SUBMITTED: SENIOR ENGINEER HEAD, DESIGN SECTION

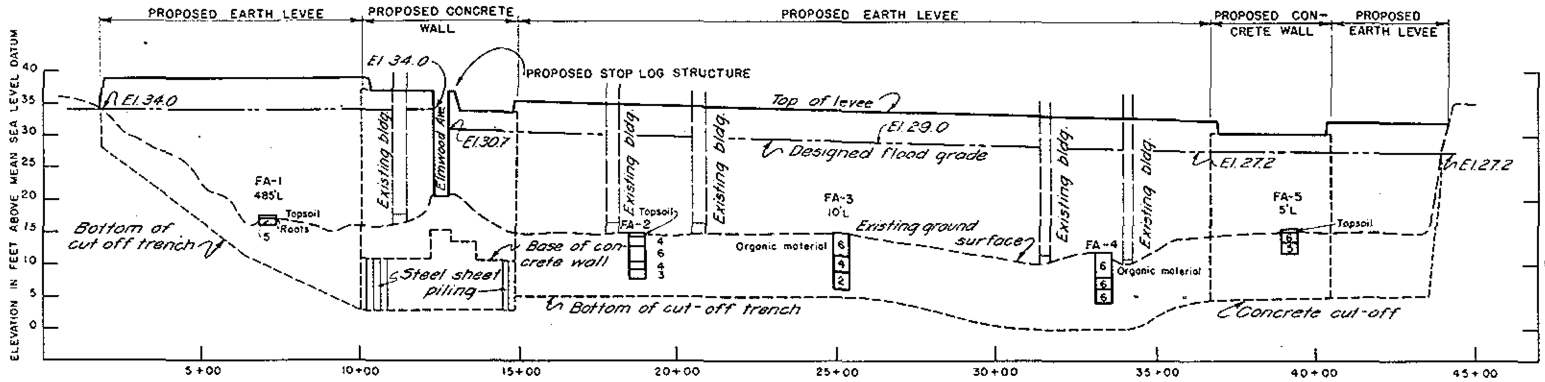
APPROVAL RECOMMENDED: PRINCIPAL ENGINEER CHIEF, F. C. ENGINEERING DIV.

APPROVED: LT. COL., CORPS OF ENGI DISTRICT ENGINEE

DESIGNED: W. R. Kolb ASST. ENGINEER

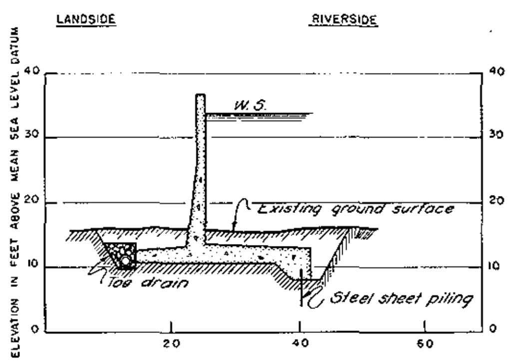
DRAWN. J.S. TRACED. C.P. CHECKED F.W.L.

FILE NO. PT-4-10C TO ACCOMPANY REPORT DATED: OCT. 20, 1939

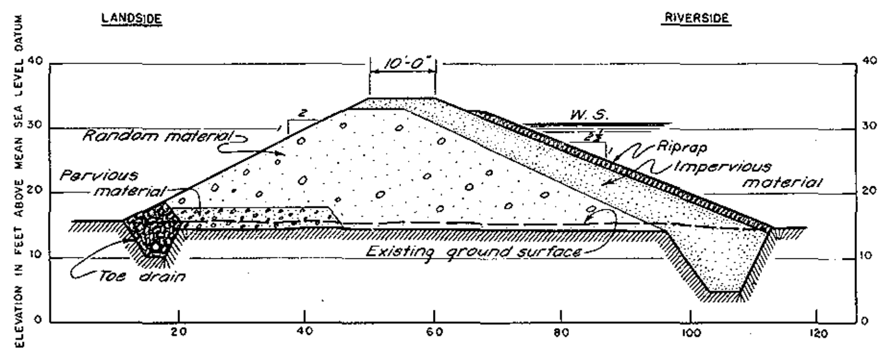


PROFILE ALONG ₵ LEVEE

SCALES: HOR. 1" = 200'-0"
VERT. 1" = 10'-0"



STA. 11+00
SCALE: 1" = 10'-0"



STA. 22+00
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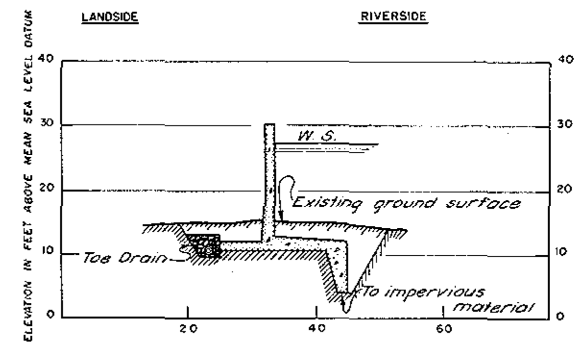


STA. 38+00
SCALE: 1" = 10'-0"

LEGEND

FA = Auger boring.

NOTES

L - indicates landside levee ₵.
R - indicates riverside levee ₵.
Freeboard used in estimates is 3 feet for levees and 1 foot for walls.

DESCRIPTION OF NUMERICAL CLASSES

1 — Variable - Graded from Gravel to Coarse Sand - Contains little medium sand.

2 — Uniform Coarse to Medium Sand - Contains little gravel and fine sand.

3 — Variable - Graded from Gravel to Medium Sand - Contains little fine sand.

4 — Uniform Medium to Fine Sand - Contains little coarse sand and coarse silt.

5 — Variable - Graded from Gravel to Fine Sand - Contains little coarse silt.

6 — Uniform Fine Sand to Coarse Silt - Contains little medium sand and medium silt.

7 — Variable - Graded from Gravel to Coarse Silt - Contains little medium silt.

8 — Uniform Coarse to Medium Silt - Contains little fine sand and fine silt.

9 — Variable - Graded from Gravel to Medium Silt - Contains little fine silt.

10 — Uniform Medium to Fine Silt - Contains little coarse silt and coarse clay. Possesses behavior characteristics of silt.

10C — Uniform Medium Silt to Coarse Clay - Contains little coarse silt and medium clay. Possesses behavior characteristics of clay.

11 — Variable - Graded from Gravel or Coarse Sand to Fine Silt - Contains little coarse clay.

12 — Uniform Fine Silt to Clay - Contains little medium silt and fine clay (colloids). Possesses behavior characteristics of silt.

12C — Uniform Clay - Contains little silt. Possesses behavior characteristics of clay.

13 — Variable - Graded from Coarse Sand to Clay - Contains little fine clay (colloids). Posseses behavior characteristics of silt.

13C — Variable Clay - Graded from sand to fine clay (colloids). Possesses behavior characteristics of clay.

KEY	DATE	REVISION (Indicated by △)	REV. BY	CK. BY	AP. BY

PAWTUXET RIVER FLOOD CONTROL

WARWICK LEVEE

PROFILE AND SECTIONS

PAWTUXET RIVER — RHODE ISLAN

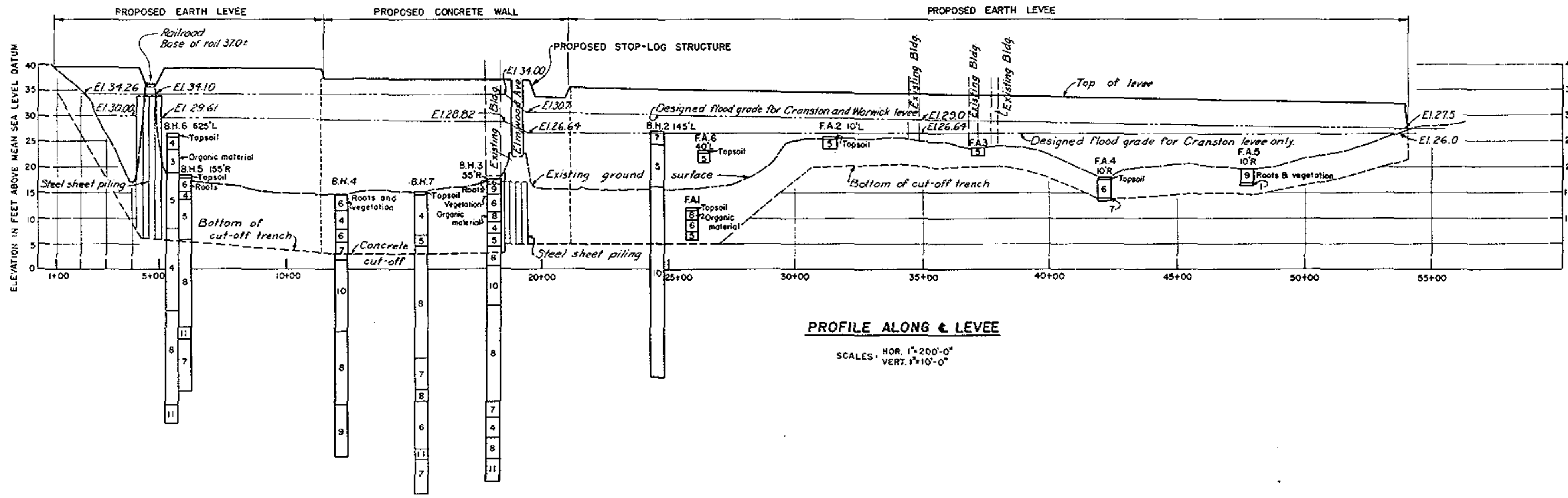
IN 3 SHEETS — SCALE: 1 IN. = 10 FT. — SHEET NO.

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT. 1

SUBMITTED: [signature] SENIOR ENGINEER, HEAD, DESIGN SECTION
APPROVAL RECOMMENDED: T S Burns, PRINCIPAL ENGINEER, CHIEF, F. C. ENGINEERING DIV.
APPROVED: [signature] LT. COL., CORPS OF ENGI... DISTRICT ENGINEER

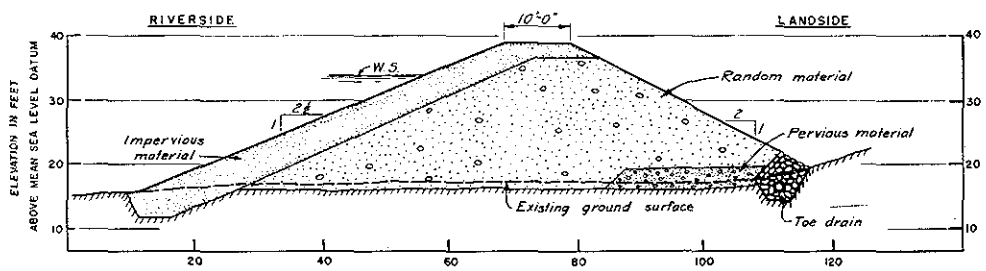
DESIGNED: W. R. Kaltfleisch, ASST. ENGINEER
DRAWN: J. S.
TRACED: O. A. K.
CHECKED: F. W. L.

FILE NO. PT-4-100
TO ACCOMPANY REPORT
DATED: OCT. 20, 1939



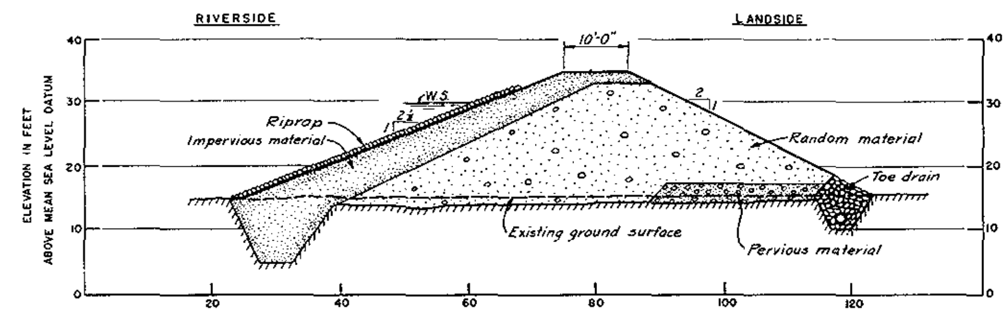
PROFILE ALONG ℄ LEVEE

SCALES: HOR. 1"=200'-0" VERT. 1"=10'-0"



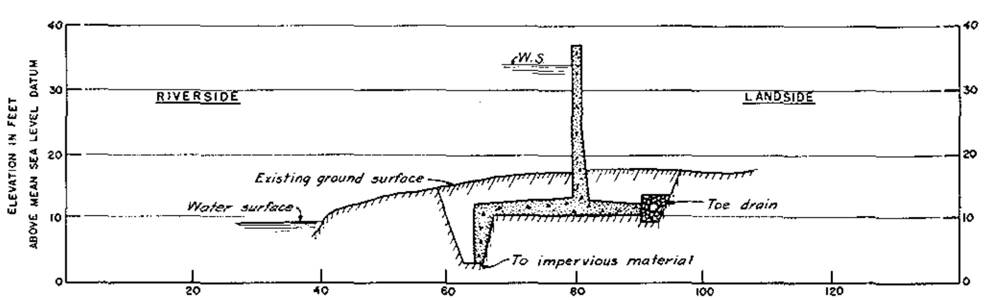
STA. 4+00

SCALE: 1"=10'-0"



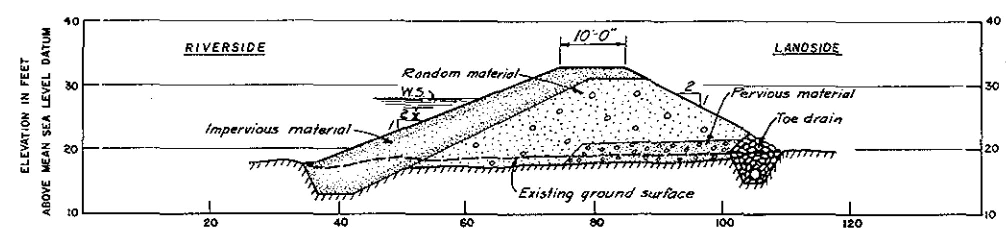
STA. 25+00

SCALE: 1"=10'-0"



STA. 15+00

SCALE: 1"=10'-0"



STA. 47+00

SCALE: 1"=10'-0"

LEGEND

BH = Drive sample bore hole.
FA = Auger boring.

NOTES

For general notes and descrip of numerical classes see Plate 6
Freeboard used in estimates is feet for levees and 1 foot for wall

KEY	DATE	REVISION (Indicated by Δ)	REV BY	CK BY	AP BY

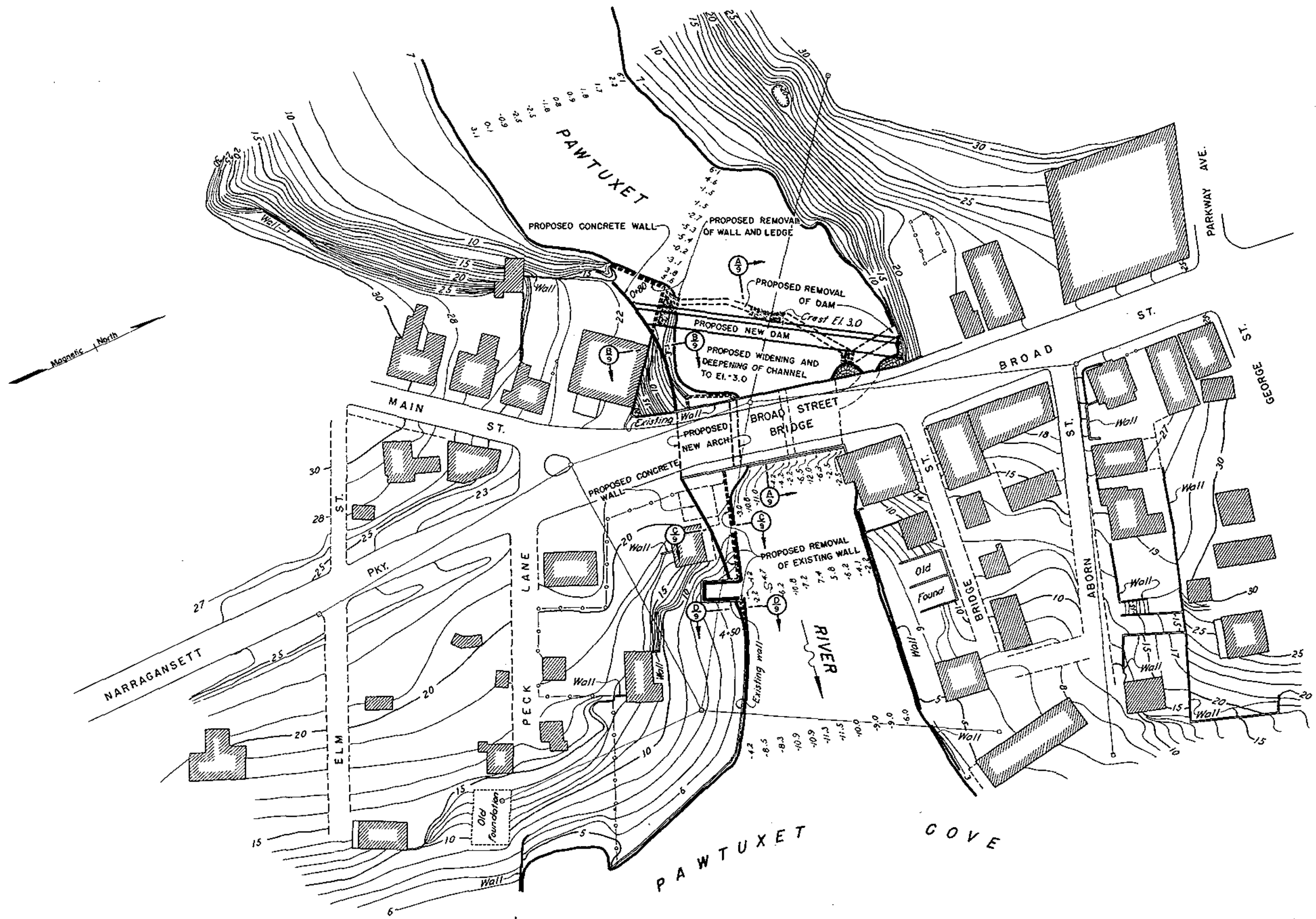
PAWTUXET RIVER FLOOD CONTROL

CRANSTON LEVEE

PROFILE AND SECTIONS

PAWTUXET RIVER — RHODE ISLAN
IN 3 SHEETS — SCALE: 1 IN. = 10 FT. — SHEET NO.
U. S. ENGINEER OFFICE, PROVIDENCE, R. I. — OCT. 1

SUBMITTED: SENIOR ENGINEER, HEAD, DESIGN SECTION
APPROVAL RECOMMENDED: T. S. Burns, PRINCIPAL ENGINEER, CHIEF, F. C. ENGINEERING DIV.
APPROVED: LT. COL., CORPS OF ENGI, DISTRICT ENGINEE
DESIGNED: W. R. Kalbfleisch, ASS'T. ENGINEER
DRAWN: J.S. TRACED: H.S.L. CHECKED: G.L.H.
FILE NO. PT-4-100 TO ACCOMPANY REPORT DATED OCT 20, 1939



PLAN

NOTES
For location of project see Plate 1.

KEY	DATE	REVISION (Indicated by △)	REV BY	CK BY	AP BY

PAWTUXET RIVER FLOOD CONTROL
BROAD STREET IMPROVEMENTS
GENERAL PLAN

PAWTUXET RIVER — RHODE ISLA

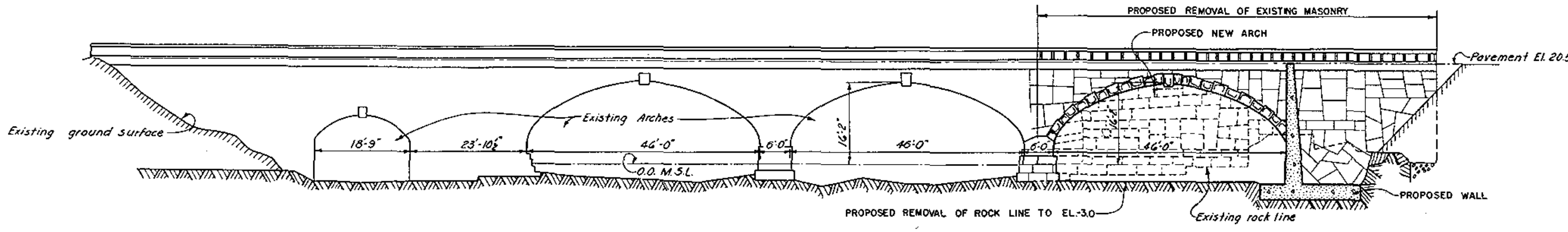
IN 2 SHEETS — SCALE: 1 IN. = 40 FT. — SHEET NO.

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT

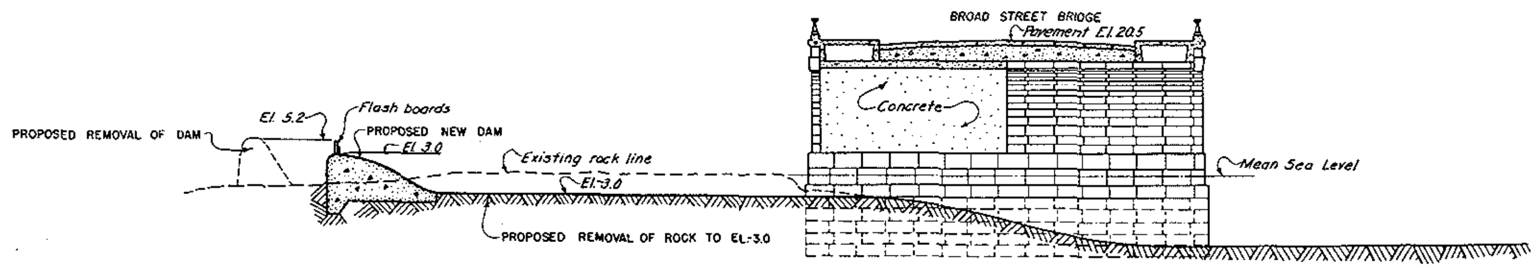
SUBMITTED: SENIOR ENGINEER, HEAD, DESIGN SECTION
APPROVAL RECOMMENDED: T. S. Burns, PRINCIPAL ENGINEER, CHIEF, F. C. ENGINEERING DIV.
APPROVED: LT. COL., CORPS OF E., DISTRICT ENGIN

DESIGNED: W. P. Kohlfleisch, ASST. ENGINEER
DRAWN: J.S. TRACED: H.M.T. CHECKED: W.S.G.

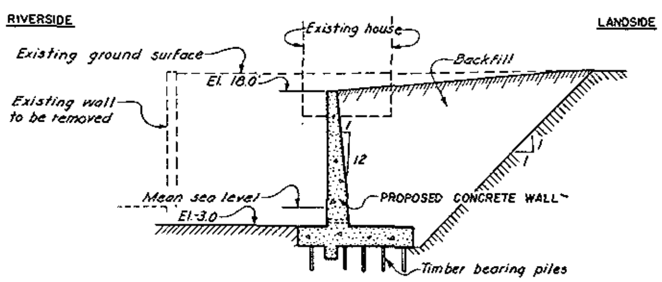
FILE NO. PT-4-I
TO ACCOMPANY REPORT DATED: OCT. 20, 1939



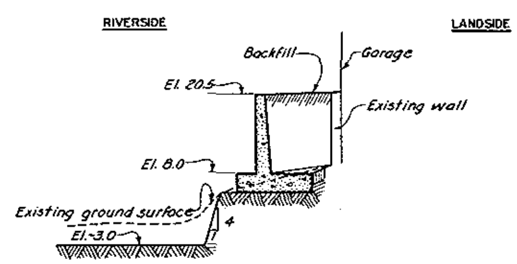
ELEVATION OF BRIDGE LOOKING DOWNSTREAM



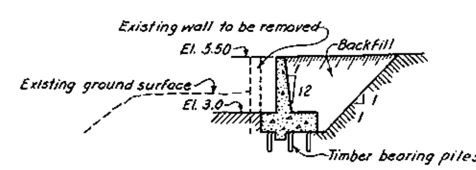
SECTION $\frac{A}{8}$



SECTION $\frac{C}{8}$



SECTION $\frac{B}{8}$



SECTION $\frac{D}{8}$

KEY	DATE	REVISION (indicated by △)	REV.BY	CK.BY	AP.BY

PAWTUXET RIVER FLOOD CONTROL

BROAD STREET IMPROVEMENTS

PROFILE AND SECTIONS

PAWTUXET RIVER — RHODE ISLA

IN 2 SHEETS — SCALE: 1 IN.= 10 FT. — SHEET NO.

U. S. ENGINEER OFFICE, PROVIDENCE, R. I., OCT.

SUBMITTED: [signature] SENIOR ENGINEER, HEAD, DESIGN SECTION

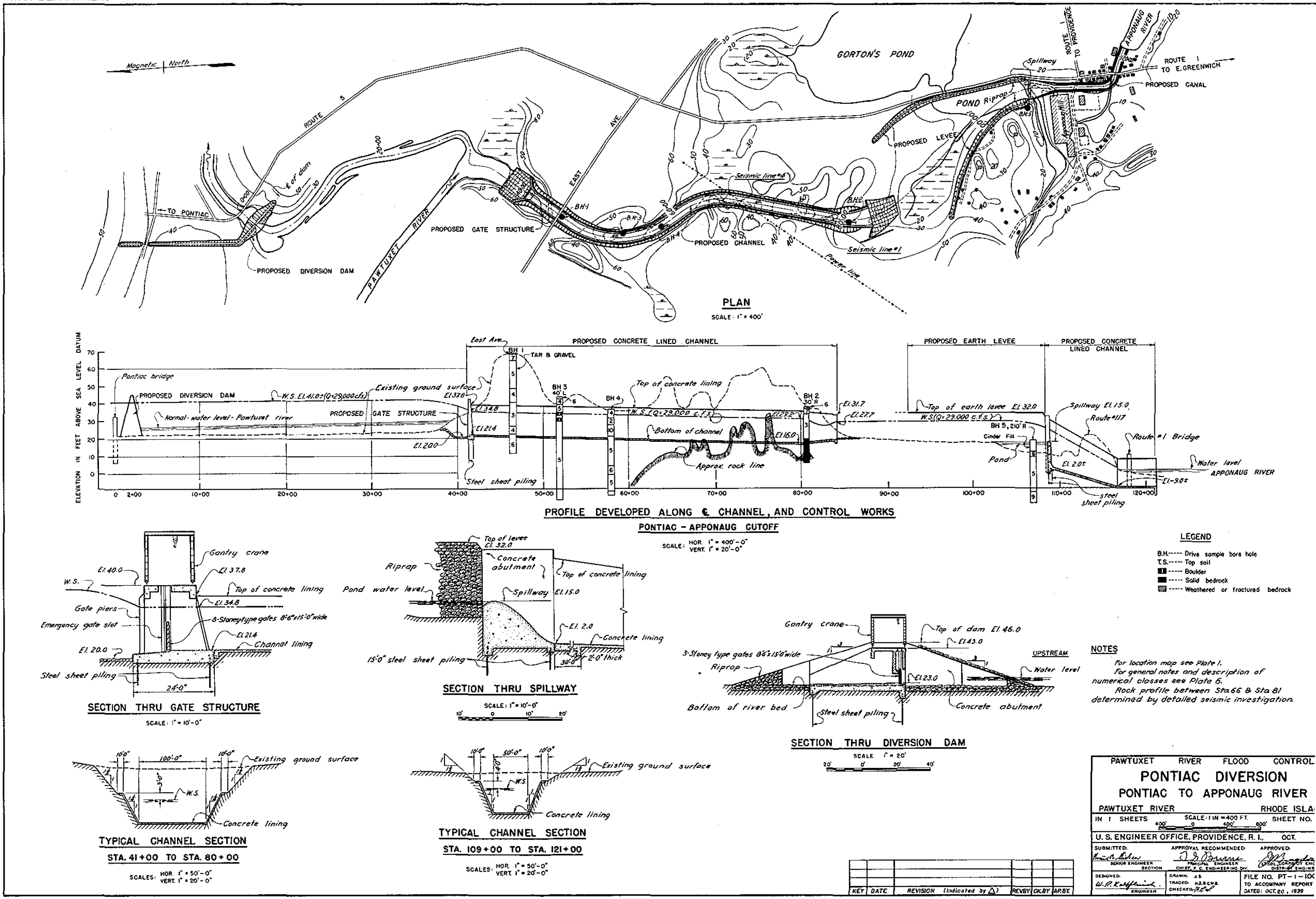
APPROVAL RECOMMENDED: [signature] PRINCIPAL ENGINEER, CHIEF, F. C. ENGINEERING DIV.

APPROVED: [signature] COL., CORPS OF ENG., DISTRICT ENGINE

DESIGNED: W. E. Kalfflmich ASST. ENGINEER

DRAWN. J.S.
TRACED. H.R.-H.O.W.
CHECKED H.R.S.

FILE NO. PT-4-10
TO ACCOMPANY REPORT DATED: OCT 20, 1939


Magnetic North
GORTON'S POND
POND
Riprap
Spillway
ROUTE 1 TO PROVIDENCE
APPONAUG RIVER
ROUTE 1 TO E. GREENWICH
PROPOSED CANAL
PROPOSED LEVEE
ROUTE 5
EAST AVE.
TO PONTIAC
℄ of dam
PROPOSED DIVERSION DAM
PAWTUXET RIVER
PROPOSED GATE STRUCTURE
PROPOSED CHANNEL
Seismic line #1
Seismic line #4
Power line
PLAN
SCALE: 1" = 400'
ELEVATION IN FEET ABOVE SEA LEVEL DATUM
Pontiac bridge
PROPOSED DIVERSION DAM
W.S. El. 41.0± (Q=29,000 cfs)
Existing ground surface
Normal water level - Pawtuxet river
PROPOSED GATE STRUCTURE
East Ave.
PROPOSED CONCRETE LINED CHANNEL
TAR & GRAVEL
Top of concrete lining
W.S. (Q=29,000 c.f.s.)
Bottom of channel
Approx. rock line
Steel sheet piling
PROPOSED EARTH LEVEE
PROPOSED CONCRETE LINED CHANNEL
Top of earth levee El. 32.0
W.S. (Q=29,000 c.f.s.)
Spillway El. 15.0
Route #117
Route #1 Bridge
Water level APPONAUG RIVER
Cinder Fill
Pond
steel sheet piling
PROFILE DEVELOPED ALONG ℄ CHANNEL, AND CONTROL WORKS
PONTIAC - APPONAUG CUTOFF
SCALE: HOR. 1" = 400'-0" VERT. 1" = 20'-0"
LEGEND
B.H. ---- Drive sample bore hole
T.S. ---- Top soil
---- Boulder
---- Solid bedrock
---- Weathered or fractured bedrock
Gantry crane
W.S.
Top of concrete lining
Gate piers
8-Stoney-type gates 8'-6" x 15'-0" wide
Emergency gate slot
Channel lining
Steel sheet piling
SECTION THRU GATE STRUCTURE
SCALE: 1" = 10'-0"
Top of levee El. 32.0
Concrete abutment
Riprap
Top of concrete lining
Pond water level
Spillway El. 15.0
Concrete lining
15'-0" steel sheet piling
2'-0" thick
SECTION THRU SPILLWAY
SCALE: 1" = 10'-0"
Gantry crane
Top of dam El. 46.0
3-Stoney type gates 8'-6" x 15'-0" wide
Riprap
UPSTREAM
Water level
Bottom of river bed
Steel sheet piling
Concrete abutment
SECTION THRU DIVERSION DAM
SCALE 1" = 20'
NOTES
For location map see Plate 1.
For general notes and description of numerical classes see Plate 6.
Rock profile between Sta. 66 & Sta. 81 determined by detailed seismic investigation.
Existing ground surface
Concrete lining
TYPICAL CHANNEL SECTION
STA. 41+00 TO STA. 80+00
SCALES: HOR. 1" = 50'-0" VERT. 1" = 20'-0"
Existing ground surface
Concrete lining
TYPICAL CHANNEL SECTION
STA. 109+00 TO STA. 121+00
SCALES: HOR. 1" = 50'-0" VERT. 1" = 20'-0"
KEY DATE REVISION (Indicated by △) REV.BY CK.BY AP.BY
PAWTUXET RIVER FLOOD CONTROL
PONTIAC DIVERSION
PONTIAC TO APPONAUG RIVER
PAWTUXET RIVER RHODE ISLA
IN 1 SHEETS SCALE: 1 IN = 400 FT. SHEET NO.
U. S. ENGINEER OFFICE, PROVIDENCE, R. I. OCT.
SUBMITTED: SENIOR ENGINEER SECTION
APPROVAL RECOMMENDED: PRINCIPAL ENGINEER CHIEF, F. C. ENGINEERING DIV.
APPROVED:
DESIGNED: ENGINEER
DRAWN: TRACED: CHECKED:
FILE NO. PT-1-10
TO ACCOMPANY REPORT DATED: OCT. 20, 1939